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Studies of Reproductive Elements.

I. Spermatogenesis, Ovogenesis, and Fertilization in *Diaptomus* sp.

By

C. Ishikawa, *Ph. D., Rigakuhakushi.*

Professor of Zoology, Agricultural College, Imperial University.

With Pl. I.

A. DESCRIPTIVE PART.

The species of *Diaptomus* on which the following observations were made is very abundantly found in an old pond in the University grounds. Its breeding occurs repeatedly at an interval of about two months during the colder half of the year.

1. Testicular Sac.

By examining the testis under a microscope, we are struck with the variety of cellular elements found in it. Near to its two ends we find cells in active division, while its median part is filled with cells whose nuclei are in the resting stage. We can therefore divide the entire sac into different zones just as has been done by *Ed. van Beneden* and *Julin*,[1] and lately by *O. Hertwig*,[13] with the testis of *Ascaris megalocephala*. Following the example of these authors we shall speak of the blind end as the *formative zone*, the middle part as the *growing zone*, and the part near the vas-deferens as the *zone of ripening*.

In the formative zone, the nuclei are tolerably large, and with

very little protoplasm. The chromatic elements are very much elongated and appear as so many minute rods. Many of the cells are in the state of division.

In the growing zone ("Wachsthumszone") the nuclei recede to the state of rest, and the germ-cells grow to nearly double their size after division in the first zone. This stage is, however, not so well marked in this animal as in *Ascaris*; we can nevertheless distinguish it pretty easily by the absence in it of karyokinetic figures.

And in the last zone we find again the active multiplication of the cells. "Jede Zelle zerfällt jetzt durch zwei Theilungen, die sich unmittelbar aneinander anschliessen, in 4 Elemente, welche sich direct zu den befruchtenden Samenkörpern umbilden."[13]

Fig. 1. represents a longitudinal section of a testicular sac not very highly magnified, the lower end of the figure showing the blind posterior end and the upper end the place where the vas deferens takes its origin. The three zones here enumerated can be clearly seen even by this figure. The entire lower third of the sac represents the formative zone in which are seen a few cells in division. The next zone is well characterized by the peculiar appearance of the chromatic elements and occupies the middle portion of the sac, while the last zone or the zone of ripening is seen at the anterior end, well characterized by the presence of many karyokinetic figures in it.

a. The Formative Zone.—This zone occupies nearly one-third of the entire testicular sac near its posterior end. The cells in this part are found partly in the state of division and partly in the state of the so-called "skein" stage (Knäuelstadium), showing thus very clearly that these are in active multiplication, as stated above (fig. 1 & fig. 2). The chromatic elements of the nuclei in the "skein" stage are found to be of very different thicknesses, owing to the different stages in which we observe them; and their number

could not be exactly made out, except in the stages just before and during the division. At this stage each chromatic element assumes at first a rod-like shape, and then becomes constricted in its median portion, transversely to its long axis, thus resembling in shape a dumb-bell (fig. 2, left end). These dumb-bell shaped bodies are eight in number, and arrange themselves in form of a ring on whose periphery they lie. This is the stage of the spindle. It will be noted that the spindle appears different to the eye according to the methods of preservation we use. Thus preparations treated with hot-alcoholic sublimate (30 % alcohol to which a few drops of concentrated sublimate solution have been added) show no achromatic fibres connected with the chromatic elements, while those cells which are killed with aceto-picric-acid exhibit them very distinctly. The central bodies can also be clearly made out with Grenacher's haematoxylin. In the process of division each dumb-bell shaped chromosome elongates and becomes divided in its middle part, so that one half of the dumb-bell goes to one pole and the other half to the other. The two daughter cells arising by division of a mother cell contain each eight single chromosomes, each of which is half one of the original chromosomes. The only difference from the ordinary karyokinesis consists in the mode of division of the chromosomes, which generally divide longitudinally and not transversely.

Fig. 2 represents more highly magnified the extreme posterior end of the testis shown in fig. 1. We now see a number of primitive sperm-cells with very large nuclei, the chromatic elements of which appear as so many minute rods. At the left hand corner is seen one of the cells in division, in which five dumb-bell-shaped chromosomes are represented in a single row at the equator of the spindle; the other three, not here visible because lying at a lower level, could be made out by focussing the microscope. At the right hand I have

drawn from the testis of another individual, a cell found in this region which represents a further stage of division, in which the chromatic elements are already separated from each other and lie near the poles of the spindle. I will call these primitive cells by the name of *primary spermatic cells* ("Ursamenzellen" of German authors). They generally divide two or three times, and thus give rise to the cells of the growing zone which will be spoken of as *sperm-mother-cells* ("Samenmutterzellen" of German authors).

b. The Growing Zone.—The cells at the beginning of this zone are relatively small and the eight chromosomes begin gradually to elongate and at the same time the nuclear membrane becomes distinct. Hand in hand with this change the cell-body enlarges, while the nucleus appears to get smaller and more compact, colouring very deeply with reagents, and at last becomes quite homogeneous, owing to the thick consolidation of the chromosomes. These stages are seen in figs. 3, 4, and 5. In fig. 3 the chromatic elements are just beginning to elongate, have continued to change in cells represented by fig. 4, and lastly in fig. 5 have become quite homogeneous.

The next change in the cells is the dissolution again of the elements (figs. 6 and 7, the former representing the polar view and the latter that from the side). Instead of a homogeneous mass we now see a number of elongated chromosomes irregularly lying in the centre of a cell, but generally more or less gathered to one side reminding one remarkably of the figures given by *Hertwig* in the same stages of development in the spermatic cells of *Ascaris megalocephala*. The only difference between them and our figures consists in the absence of a nuclear membrane in the latter. The chromosomes become shorter and thicker and assume at last a short rod-like shape just as we find them in primary spermatic cells preparing to divide. Fig. 8 represents these changes. At the left hand of the figure is

seen a cell whose chromatic elements are somewhat shorter than those represented in fig. 6, and one at the right shows distinctly eight short chromatic rods.

The sperm mother-cells increase all the while in size up to the stage which we have called the zone of ripening ("Reifezone"), and which we will now proceed to describe.

c. The Zone of Ripening.—The eight chromatic rods now begin to be constricted at their middle point giving rise to eight dumb-bell-shaped bodies as before. These arrange themselves in the shape of a ring and each of them becomes divided into halves on the appearance of achromatic fibres as before (figs. 9, 10, and 11). In fig. 9 which is drawn from a specimen killed with hot picro-acetic solution, the eight chromatic elements are beginning to divide transversely, while in the cells represented by figs. 10 and 11 (treated with acetic acid solution of methylgreen) the division has proceeded a little farther. The large size of the cells represented by these figures is due perhaps to the pressure exerted upon them by the cover-glass. The cells resulting from this division contain therefore each eight single chromosomes, which now prepare to *divide directly without an intervening resting stage.* The eight single chromosomes in each of the cells after the division, arrange themselves in one plane, and mostly at the periphery of a ring as usual, but sometimes one or two chromosomes can be found in the interior of the ring. These cells now begin to be divided into two on the appearance of the attractive sphere, central bodies, etc., as usual in the karyokinetic cell division, but with this important difference concerning the chromosomes, that *each chromosome does not become divided into two as usual, but remains undivided during the division, so that four of the eight go bodily into one cell and the other four into the other.*

Figs. 12, 13, 14, 15, and 16 represent these changes. In fig. 12,

which is drawn from a specimen treated with acetic acid solution of methylgreen, and shows the eight single chromosomes in the equatorial zone of a spindle. five of these are seen on one side while the other three lie on the other side. The cell body appears to be larger than those represented by figs 13, 14, and 15, which are taken from a specimen treated with picro-acetic acid solution. This difference in size is due partly to the pressure of the cover glass, but chiefly to the action of the acetic acid. Fig. 13 shows the polar view of a spindle at the stage of fig. 12. Of the eight chromosomes, seven lie at the periphery and one in the middle of a circle. In fig. 14 a similar spindle seen from the side is represented, while fig. 15 shows the cell-divsion nearly completed, four chromatic elements being drawn to one pole and four to the other pole. The cell-body is also nearly at the end-stage of its division. A similar stage is represented more clearly by fig. 16.

The nucleus of a cell after this division again acquires a membrane and the chromosomes become also indistinguishable, colouring very deeply and uniformly. At a place a little farther outward the nucleus again becomes uneven to the staining, and shows more or less distinctly indications of chromosomes coming to occupy positions at the periphery of the nucleus whose central part now shows a clear space. In this condition the sperm cells again begin to grow gradually, and the chromosomes come again to be seen more or less distinctly as very fine threads and lying rather irregularly in the nucleus. In this growth of the cell, the nucleus progresses more than the cell body, so that the latter becomes proportionally much reduced, and when the cell passes into the vas deferens no trace of the cell-body can be detected. The nucleus now assumes the characteristic elongated shape we find in the sperm cells contained in the spermatophore sac attached near the female opening. Illustrations of these changes are

seen in figs. 16, 17, 18, 19, 20, 21, and 22, which are drawn from a testis and vas deferens of one and the same individual under the same magnifying power.

2. *The Ovarian Sac.*

The ovary of *Diaptomus* I examined, consisted of a median unpaired part—the ovary proper—and the oviducts arising on both sides of it. For the sake of convenience I have divided the contents of the ovary into three different zones as in the case of the testicular sac, although the distinctions are here not so complete as in the latter: *a*) *the formative zone* which occupies the extreme blind end of the sac; *b*) *the growing zone* filling the rest of the whole ovarian sac and part of the oviducts; and *c*) *the zone of ripening* occupying the oviducts alone. In fact the process of ripening does not end within the body of the animal: the second polar body, as was first observed by *Grobben*,[8] is formed after the eggs have been laid in the breeding-sac and attached to the base of the tail of a female. The ripening zone moreover overlaps the hinder part of the second zone.

a. The Formative Zone.—At the extreme blind end of the ovarian sac, which ends in a very narrow tube containing but a single row of germ-cells, we meet with cells quite similar to those we find in the posterior third of a testis. A comparison of figs. 23 and 24 with fig. 2 of the testis will at once show this similarity. In these cells of the ovarian sac, too, a relatively large nucleus contains chromatic nets which are certainly in the "skein" stage, but the karyokinetic figures are very scantily to be seen. Next follow the cells which to all appearance seem to correspond with the testicular cells as represented in fig. 3 and which are apparently in the beginning of a *dispiremstage*. The chromatic fibres become finer and finer till they appear as minute dots

in the nucleus; at the same time a nucleolus appears within the nucleus and the egg gets into the next or the *growing zone*.

b. The Growing Zone.—Strictly speaking this zone begins from the point where the germ-cells get into the dispirem stage. The nuclear threads which now appear as minute dots become gradually fainter till at last they disappear completely from the view. The germinal vesicle together with the egg-cell grows larger and larger, and the germinal spot which always remains single also enlarges. As has been already stated by *Paul Mayer* of *Eupagurus*,[15] and after him by myself of *Atyephira*,[14] the growth of the germinal vesicle is relatively less than that of the cell-body.

Thus the ovary or germ-gland ("Keimdruse" of *Claus*) can also be divided into two parts in accordance with the description given by *Haecker* of *Cyclops*.[8] Just as in that case, the blind end is characterized, as above said, by the presence of a number of nuclei in division. This is the "erste Phase der Ovogenese" of *Haecker* and my formative zone. It is followed by the second part, the growing zone, which extends from here to the distal end of the oviducts. Here are passed two important stages of ovogenesis, the first of which is characterized by the appearance of a nucleolus within the nucleus and the disappearance of the chromosomes, and the second by the formation of the yolk-granules, and along with this the rapid enlargement of the germinal cells. It will perhaps be better to recognise in this zone two parts according to the stages of development of germ cells, as is done by *Haecker*, who takes as the first part that portion of a germ gland where the nuclear membrane appears and the contour of the nuclear thread becomes indistinct, and "zugleich findet sich ein Nucleolus vor, der Hand in Hand mit der Verwischung der Schleifenindividualität an Grösse zunimmt. Neben diesem grossen Nucleolus zeigen sich schon in sehr jungen Keimzellen regelmässig ein oder

zwei runde Körper, die ich vorläufig als Micronucleolen bezeichnen möchte." This, as will be seen from my figures, corresponds exactly with what I have seen in the egg-cells of *Diaptomus*, the sole difference lying in the absence of the small bodies besides the nucleolus which he calls micronucleoli. These appear, in my case, first in eggs that are nearly ripe, and shortly before the formation of the first polar body, as will be seen later on.

In fig. 24, which represents a part of an ovarian sac, are seen on the right the cells of the formative zone, which towards the left gradually pass over into those of the growing zone. The chromatic elements, as will be seen, disappear as we pass from the blind end outward, while a distinct nucleolus comes into view.

The formation of yolk-granules and consequently the rapid development of germ-cells takes place first when the eggs get into the oviduct, just as in the case of *Cyclops*. As in that case also, all the egg-cells in the oviduct are at a given time in one and the same stage of development. *Haecker* says on this point: "die sämmtlichen Eizellen des nämlichen Individuums" are found "stets auf fast vollkommenen gleicher Entwicklungsstufe."

Of the origin of yolk granules I have not much to say. They originate, as I stated of the eggs of *Atyephira*, in the body of the egg-cell near the periphery rather than near the centre.

The next change in the development of the egg-cells is the appearance of a number of small bodies in the nucleus, besides the nucleolus, which correspond with the "Micronucleolen" of *Haecker;* there appear at the same time a number of dumb-bell shaped chromosomes exactly corresponding with those found in the spermatic cells. The nucleolus at this time is found to be much reduced in size and it shows very often a number of vacuoles of variable sizes. Like *Haecker* I am also at a loss to know whether the micronucleoli arise

from the nucleolus or independently in the nuclear plasma. At all events the nucleolus here is in stages of regressive metamorphosis, and in many cells in these stages no trace of it can be seen within the nucleus. As with the similar developmental stages of spermatic cells, I will call the stage after this the *zone of ripening*.

Fig. 25 shows two neighbouring eggs of an animal in which the eight dumb-bell shaped chromatic elements have appeared. The germinal vesicle has now attained its largest size. In one of them, on the left hand side of the figure, we see besides the eight chromatic elements a germinal spot, (now greatly reduced in size), and nine small round vesicular bodies which certainly correspond to the micronucleoli of *Haecker*. In the germinal vesicle of the other egg, the germinal spot is no more to be seen. This figure is compounded from three successive sections, in such a manner that from the first and second sections the egg on the left side is drawn, while from the second and third sections that on the right side is drawn.

c. The Zone of Ripening.—As already stated, there is no distinction between the eggs in the last zone and those in the zone of ripening, and the eggs go through, in one and the same zone, the changes mentioned under the heading of the growing zone and the changes that are now to be mentioned; so that these two zones are not distinct in the ovarian sac, as they are in the testicular sac. The only reason for counting them separate consists in the advantage obtained when we come to compare these two kinds of germ cells together.

The egg cells, as mentioned above, now show distinct chromatic elements each in the shape of a dumb-bell. These are eight in number and are scattered about without any order in the nucleus. Shortly after the appearance of the chromatic elements the micronucleoli as well as the nucleolus disappear, and the nuclear membrane becomes also indistinct and finally disappears.

The eight chromosomes now arrange themselves on the periphery of a circle just as in the case of spermatic cells. The attractive sphere and the central bodies are not, as in the testicular cells, to be observed in preparations treated with sublimate-alcohol, but are very distinct in the cells killed with picro-acetic acid. Figs. 26-29 give the eggs in these stages. Fig. 26 represents only the small part of an egg, in which the spindle lies. The nuclear membrane has already disappeared, and no trace of the germinal spot and the micronucleoli is to be seen. Five of the dumb-bell-shaped chromosomes are seen in a curved row from this side, and the three others can be seen, by focussing the microscope, below these. In fig. 27 we have a polar view of such a spindle, while fig. 28 gives another spindle as seen from the side. These three figures are drawn from preparations treated with hot sublimate alcohol, and no trace of achromatic fibres is to be seen. Fig. 29 gives the spindle in the same stage as that of figs. 26, 27, and 28, but treated with picro-acetic acid. Here we see not only the achromatic fibres, but also a trace of the vesicular membrane quite distinctly.

This spindle is that of the first polar body, and travels gradually towards the surface of the egg, where each chromosome begins to divide transversely just as in the first division of testicular cells in the zone of ripening. This division gives rise to the first polar body, which is thrown out of the egg, while this is still in the oviduct. There are thus *eight chromosomes in the first polar body and the same number in the other half of the germinal vesicle which remains in the egg.* The latter begins to divide directly, but now in such a manner *that four of the eight chromosomes are separated off from the other four.* This is the formation of the second polar body, which thus exactly corresponds with the last division of the spermatic cells, as has been shown by *Platner*[16] in *Aulacostoma* and by *Hertwig*[12] in *Ascaris* eggs. These stages are represented by figs. 30-35. In fig. 30 the spindle of the second polar body

is seen from the pole. The eight single chromosomes are clearly to be seen lying in the equatorial plane of the spindle. The first polar body is no more to be seen. Figs. 31, 32, and 33 show the spindle in more advanced stages. In the first two figures the chromatic elements are still very short, but in the last (fig. 33) they are rather elongated. Figs. 34 and 35 show the stage where the second polar body has entirely separated from the egg nucleus, which latter has now acquired a vesicular form. The four chromatic elements are more or less distinctly to be seen in the second polar body.

At the stage between the expulsion of the first and the second polar bodies the egg passes out of the oviduct into the breeding sac, so that the first polar body lies outside the egg-membrane, which is formed after its expulsion, and after the penetration of a spermatic cell into the egg, which takes place at the extreme distal end of the oviduct. That in *Copepoda* the first polar body lies outside the egg-membrane and therefore is not to be found in eggs that have come out of the oviduct was first shown by *Grobben*[8] in *Cetochilus* and afterwards by *M. Nussbaum*[16] in many *Cirripedæ*, in which it had been foreseen by *Weismann*.

3. *A Comparison of the Ripening Phenomena in Egg- and Sperm-cells.*

As is shown in preceding pages the correspondence in the development of the egg-cell and of the spermatic-cell is nearly as complete as in *Ascaris*, upon which *O. Hertwig*[13] has made a series of very fine observations. I say "nearly as complete," because here the corresponding zones are not so easy of comparison together as in the case of *Ascaris*. We can, however, follow them in each of the developmental phases, as we shall presently see.

a. The Formative Zone.—As above stated this zone is exactly alike in both sacs. The sizes of the germinal cells, their nuclei, and their chromatic fibres are so alike in the two sexes, that it would be difficult to say whether they belong to an ovary or to a testis. The only difference between them is that this zone is much shorter in ovary than in testis, and that more karyokinetic cell-divisions are present in the latter than in the former. *Haecker*[8] was also not able to see any "Mitose" in this region of the ovary of *Cyclops*, but he does not hesitate to affirm that such occurs here. A comparison of figs. 1 and 2 of the testicular sac with figs. 23 and 24 of the ovary will show the resemblance beyond all doubt.

b. The Growing Zone.—There appears in this zone a great difference between the egg- and spermatic-cells, just as in the case of *Ascaris*, of which *Hertwig*[13] says:—

"In diesem zweiten Abschnitt der Geschlectsröhren treten in der Anordnung der Eier und Samenzellen erhebliche Verschiedenheiten hervor. Erstere nehmen an Grösse ausserordentlich zu und ordnen sich dabei in einfacher Lage um eine central gelegene Rhachis an. Die Samenzellen dagegen, die sich zwar auch, aber in Vergleich zu den Eiern viel weniger vergrössern, sitzen zahlreichen Rhachislamellen mit Protoplasmafäden auf, ..."

This difference between the egg- and spermatic-cells in *Diaptomus* is still greater than in *Ascaris*, where the spermatic cells become also loaded with yolk-granules like the egg-cells, and grow to two to four times their original mass, whereas in *Diaptomus* the growth is very limited. But this difference in size is a point of no great importance in comparison with the much greater similarity existing between these two elements, in the complete disappearance of chromosomes and the resting condition of nuclei in both sexes. Here again occurs a slight difference between the two in regard to the

absence or presence of nucleoli, as stated above, and this I think we shall be able to explain by the difference in growth between the two kinds of cells.

c. The Zone of Ripening.—This is the most important zone for us, because we find here in both egg- and spermatic-cells a kind of cell-division that we find nowhere else. This is the occurrence of *two successive nuclear divisions without an intervening resting stage and the reduction into half of the number of chromosomes in the second of these divisions.*

As observed first by *Platner*,[18] so far as my knowledge goes, and recently to a much greater extent by *Hertwig*[13] in *Ascaris megalocephala*, there occurs no case of such a division except in the genital cells, so that these processes can rightly be looked upon as corresponding stages of the egg- and spermatic-cells *(Platner, Hertwig).*

The nuclei that have been resting for some time in the last stage begin to be active in this stage. The chromosomes gradually come into view and begin to arrange themselves in a circle under the influence (?) of the attractive centres which also now appear. The number of chromosomes I counted to be eight. In the spermatic cells we can follow the steps from their dissolution and their gradual shortening till the formation of dumb-bell shaped figures. But in the case of eggs the first distinct appearance of the chromosomes shows them already to be in that form. The division of these produces two cells of equal size in the case of the male elements, while in that of the female one of the resulting cells is much larger than the other, and thus are produced the egg and the first polar body. In all cases, however, the resulting cells contain each eight single chromosomes. The nuclei of these cells do not, as said before, go through the resting stage usual with a karyokinetic cell-division, but *begin to divide immediately and produce in case of spermatic cells four cells each with four chromatic*

elements. In the case of eggs this second division occurs generally only in one of these cells—the egg-cell —, while in the other—the first polar body—this division is suspended, so that there are now formed three cells of unequal sizes—a large, single egg-cell and two small polar bodies, the first of which contains eight single chromosomes, while the second polar body and the egg-cell each contains only four.

Thus there is a complete parallelism between the egg and spermatic cells. In both cases the primary germ cells contain eight single chromosomes, each of which divides transversely and produces many daughter cells—sperm mother-cells of males and ovum mother-cells of females. These contain each eight chromosomes like their mother-cells. They grow to a certain extent and then two successive cell-divisions take place in them, in both sexes, without an intervening resting stage, giving rise to four spermatozoa in one case and an egg-cell with two polar bodies in the other. There can therefore be no doubt that the egg-cell with two (or sometimes by division of the first polar body into two cells, three) polar bodies, corresponds exactly with four spermatozoa derived from a single sperm mother-cell, which again corresponds with the egg-cell before the formation of the polar bodies.

4. Fertilization.

During the formation of the second polar body the sperm-cell penetrates into the body of the egg-cell. The penetrating point seems to be quite irregular, but mostly near the place where the second polar body is placed. I have given three drawings of freshly laid eggs in the body of which a sperm cell is already present. In fig. 31 we see at the surface of an egg the second polar spindle, and near it to the right lies a spermatic nucleus, which has just penetrated into the egg ;

a small notch at the surface of the latter shows clearly the point where it entered. Both the polar spindle and the spermatic nucleus lie in a common protoplasmic mass. Figs. 32 and 33 are drawn from eggs in the same breeding sac as that from which fig. 31 is drawn. In both eggs the polar spindle is nearly in the same stage as in the egg represented by fig. 31, the only difference being that in fig. 33 it lies more in the centre of the egg, and that the chromosomes are more elongated than in the other. The position of the spermatic nucleus is, however, in both cases different. In fig. 32 it lies in the same pole of the egg as that in which the polar spindle is found, while in fig. 33 it has penetrated an opposite pole of the egg, although the path of its penetration is not to be seen in the figure.

The two nuclei resulting from the division of the second polar spindle, the nucleus of the second polar body, and the egg-nucleus, show great differences in appearance. That of the second polar body remains small and its four chromosomes coalesce into a single mass, stain very deeply by picrocarmine, haematoxylin, etc., while the nucleus of the egg soon becomes greatly enlarged, and its chromosomes show distinctly as four thread-like, V-shaped bodies (figs. 34 and 35). At first their number is quite distinct, but soon the chromosomes elongate, become twisted and send out many processes which anastomose with one another, and their number becomes indistinct (figs. 36-40). In figs. 34 and 35 the four chromosomes are still quite distinctly to be seen. In figs. 36, 37, and 40 they have begun already to send out processes, and in figs. 38 and 39 they appear as if broken up into a great number of elements. (The nucleus on the left of the figure is in both cases the egg-nucleus).

The changes which the spermatic nucleus goes through after it has entered into the body of an egg and before its copulation with the egg-nucleus, are almost the same as those of the latter, except

during the first stages. At first the spermatic nucleus is relatively small and generally oblong, and stains very deeply and uniformly with colouring matters, but soon it shows within it a lighter space in which chromatic fibres become more or less distinct (figs. 31-33). At about the same time that the egg-nucleus begins to enlarge, the spermatic nucleus also swells up gradually, and assumes a spherical form, always remaining a little larger than that of the egg. The chromatic elements are very distinctly to be seen, but they are so much convoluted that it is very difficult to determine their number (figs. 36-40).

The nuclei of the egg and of the spermatozoa gradually approach each other till they come to lie close together (figs. 36–49), but the nuclear membranes continue distinctly visible up to the stage of the segmentation of the egg. The chromatic elements of the nuclei gradually pass, during these stages, from their so called resting stage to a state of activity again, and the individual fibres become more and more distinct. Their number is, however, no longer four but eight. Whether this is brought about by the transverse division of the elements or by a longitudinal division, I am not able to tell. Still I think I am quite justified in supposing that this doubling of the number of chromatic elements before the formation of a spindle is the same phenomenon as that observed by *Flemming*[7] and others in the division of many animal and vegetable cells, (*Flemming's* "heterotypische Form").

The entire process of the copulation of the two nuclei up to the beginning of the segmentation will be seen by looking at figs. 36-55. Fig. 36 represents only a small part of an egg in which both nuclei are to be seen lying at some distance from one another. The smaller upper one is the egg-nucleus and the larger one below is that of the spermatozoon; both are more or less in the "skein" stage. Fig. 37

shows the stage in which the nuclei are more closely placed than in the one represented in fig. 36, the right smaller one being the egg-nucleus and the left larger one that of the spermatozoon. Close to the smaller nucleus is seen a small spherical area with a minute central body in the middle of it. This evidently corresponds with the central body with the attractive sphere around it. In fig. 38 the nucleus of the egg in proportion to that of the spermatozoon is relatively larger than those shown in figs. 36 and 37, and the four chromatic elements are more or less distinctly to be seen. The central body seems now to have become divided into two bodies lying still very close to each other. The section represented by fig. 40 did not pass exactly through the plane of the nuclei, but a little obliquely to it, so that they are seen overlapping. One of the central bodies, the lower one in the figure, lies below the spermatic nucleus and is seen through it. The central bodies are now quite separated from each other.

Figs. 41–45 are made from eggs killed with *Flemming's* solution of aceto-osmo-chromic acid, the chromatic elements of the copulating nuclei are very faintly stained by haematoxylin, but the contour of the nuclei, as well as the attractive spheres are very distinctly to be seen. These are placed in all these eggs, in contradistinction to the eggs shown in figs. 37–40, nearer to those nuclei which, from their relative position to the second polar body, appear to be those of the spermatozoon. In fig. 41, besides the second polar body, lying in the body of the egg, there is the first polar body which happened by chance to be carried with the egg into the breeding sac and came to lie outside the egg-membrane, just near the place where the second polar body lies. The number of chromatic elements within the first polar body is still distinctly to be counted as eight. Figs. 42–44 show three successive stages in the nuclear copulation ; and in fig. 45 we see two nuclei closely in contact with one another, while the

spheres of attraction are found at the two poles of the plane of contact of the nuclei, which appear to be more or less elongated.

The sections represented by figs. 46–55 were all taken from eggs killed with hot 30 % alcohol to which a few drops of sublimate had been added. The chromatic elements and the attractive spheres are tolerably well to be seen, but the central body is not so clear as in the eggs killed with the picro-acetic acid solution. Fig. 46 shows the two nuclei close to one another, and the central bodies rather farther away from the nuclei than in the case represented by fig. 45. Numerous achromatic fibres are also well to be seen extending between the central bodies and the nuclei, in which are seen eight single chromosomes. In fig. 47 which is nearly in the same stage as the one represented by fig. 46, the eight chromatic elements are more elongated. The achromatic fibres from the attractive sphere on the right of the figure are attached to both the nuclei, but those from the other sphere of attraction are connected only with one of them, which therefore seems to lie nearer than the other to that sphere of attraction. This is more clearly seen in fig. 48, where we find the nucleus lying above in the figure to be pulled more by the central body on the right hand side, and that situated below more by the one on the left. The nuclear membrane, moreover, seems to have been dissolved at the pole where the achromatic fibres are attached. The eight more or less elongated chromatic bodies are seen in each of the nuclei. In fig. 49 both the nuclei are pulled equally by the central bodies and the chromatic elements are found lying at the centre of the spindle, whose achromatic fibres are now found indistinctly within the nuclei. The nuclear membrane is, however, still present except at the place of their contact. Fig. 50 shows a cross section of the nuclei in copulation as is represented by fig. 49. In fig. 51 the nuclear membrane has entirely disappeared, but the chro-

matic elements belonging to both the nuclei are still to be seen in two separate groups. In these three sections as well as in those represented by the next three figures the number of the chromatic elements is not at all clear. Fig. 52 shows a cross section of a spindle at the stage shown by fig. 51, more highly magnified. Figs. 53 and 54 are taken from the same lot of eggs as that represented by figs. 51 and 52, but the chromatic elements are fused together at the equator of the spindle, and are now no more to be distinguished as two separate groups.

Lastly in fig. 55 is found the first segmentation-spindle with the chromosomes just separating from the equatorial plane. Their number can be distinctly counted as eight in two rows, one of which at the right hand side happened to be pulled by the achromatic fibres of the left, and is seen with its one end at the right and the other at the left.

B. SUMMARY.

1. The primary sperm cells correspond exactly with the primary egg-cells. Both contain eight chromatic elements.

2. In both cells the eight chromosomes become constricted transversely giving rise to eight dumb-bell shaped bodies. These arrange themselves in an equatorial zone and begin to divide in such a manner that half of each chromosome goes to one cell and the other half to the other. This kind of cell-division takes place two or three times and the resulting cells form the mother cells of eggs or spermatozoa, as the case may be.

3. These grow considerably ; after which

4. They begin to divide as before ; each chromosome dividing

transversely. This stage corresponds in the egg to the formation of the first polar body, which takes place exactly in the same manner as that of the first division of the sperm-mother cell. In both cases the original eight chromosomes become divided into two, giving rise to the daughter cells also containing eight chromosomes (*Weismann's* "Equationstheilung").

5. This is immediately followed by another division, without an intervening resting stage of the nuclei, and by reduction in the original number of chromosomes (*Weismann's* "Reduktionstheilung"). The eight chromosomes which at first are arranged in a single row become arranged in double rows of four each, and the cell begins to divide in such a manner that four chromosomes go to one cell and the remaining four to the other.

By divisions described under No. 4 and 5 a sperm-mother cell as well as an egg-mother cell increases to four cells, which in case of the former give rise to four spermatozoa, while in that of the latter a single egg cell with two polar bodies, results (or three when the first polar body divides).

6. During the formation of the second polar body the spermatic cell enters into the egg-cell. The nucleus of the sperm cell is, as a general thing, at first rather small and colours deeply and homogeneously, but soon the differentiation sets in and the four chromosomes become distinctly visible. The nucleus of the egg-cell remaining after the formation of the second polar body—the female *pronucleus* of *Ed. van Beneden*—shows at first distinctly four elements. These soon grow longer, show many convolutions, and pass into a "skein" stage.

7. The two nuclei gradually approach one another until they come in close contact, but they do not unite into a single piece before the equatorial plate is formed. The number of chromatic elements in each of the copulating nuclei is now found to be eight, exactly double

the number present in the maternal nucleus after the expulsion of the second polar body, and in the ripe spermatozoon.

This number goes unchanged to the formation of the first segmentation spindle, which gives rise to two first segmentation spheres, each of which contains eight single chromosomes.

C. THEORETICAL CONSIDERATIONS.

Since the important publications of *Auerbach*,* *Ed. van Beneden*, *Bütschli*, the *Hertwigs*, *Fol*, etc., investigations on the phenomena of fertilization have become more and more interesting, and now after the well known theoretical treatment of this and other kindred subjects by Prof. *Weismann*,[20] the formation of genital cells, their phases of ripening, and their copulation require exact and thorough study.

The most complete work in this direction is the beautiful investigation of *O. Hertwig* on the "Vergleich der Ei und Samenbildung bei Nematoden," published about a year ago. In this work is given for the first time a clear insight into the exact parallelism existing between the egg and the sperm-cells, the mode of their development, etc., every point in which corresponds so exactly with the descriptions given in this paper, that it seems almost superfluous for me to have published them. I have deemed it, however, worth while to record the results of my own investigations because the conclusions arrived at by *Hertwig* are regarded by some authors as demanding explanations other than those he has found for them.

There are, so far as my knowledge allows me to judge, three modes by which the "Reduktionstheilung" of sexual cells takes place. *Platner*[18,19] in his various important publications on the sexual cells mentions an exceptional mode of cell-division in the last division of

sperm cells and in the formation of the second polar body. He there says: "Das allgemeine Schema für die Zelltheilung verlangt, dass der Kern nach der Theilung wieder in das Ruhestadium zurückkehrt, das heisst sich aus dem Aster der Knäuel und aus diesem das Kerngerüst wieder rekonstruiert, und so findet man es auch überall. Nur in zwei Fällen findet hiervon eine Ausnahme statt. Der erste betrifft die Bildung des zweiten Richtungskörperchens und ist genugend bekannt. Es wird hier das Ruhestadium übersprungen. Aus der innern Tochterkernplatte der ersten Richtungsspindel bildet sich sofort die zweite Richtungsspindel, und auch die in das erste Richtungskörperchen übergegangene Kernhälfte zeigt häufig das gleiche Verhalten, das heisst sie bildet sich gleichfalls sofort wieder zu einer neuen Spindel in entsprechender Weise um. Die Theilung der zweiten Richtungsspindel wird dadurch zu einer Reduktionstheilung in Bezug auf die Quantität des Kernmaterials. Der zweite Fall dürfte weniger bekannt sein; er betrifft die letzte Theilung der samenbildenden Zellen. Auch hier wird das Ruhestadium übersprungen. Die letzte Theilung schliesst sich direkt an die vorhergehende an, indem sich aus der Tochterkernplatte sofort die neue Spindel bildet. Also auch hier findet eine Reduktionstheilung der Masse nach statt." He has thus, for the first time, clearly shown the truth of *Weismann's* theoretical conclusion as to the necessary occurrence of a reduction of nuclear elements at the beginning of each ontogenesis. In his well known essay on the "Zahl der Richtungskörper," etc. Prof. *Weismann*,[20] after discussing the subject of copulation, where the ancestral plasma ought to be doubled at each process, sees the necessity of its reduction to half of its original mass. The sharp insight of *Weismann* has brought out from *van Beneden's* and *Carnoy's* work the necessity of admitting the required reduction in the formation of the second polar body. He says: "In der Ausstossung der zweiten Richtungskörpers aber wird mit Recht eine Reduktionstheilung erblickt werden, durch

welche die Hälfte der verschiedenen Ahnenkeimplasmen in Gestalt von zwei Kernschleifen ausgestossen würde." In another place he says: "Sollte ich mich aber selbst in dieser Deutung irren, so scheint mir doch die theoretische Forderung einer bei jeder Generation sich wiederholenden Reduktion der Ahnenplasmen so sicher begründet, dass die Vorgänge, durch welche dieselbe bewirkt wird, gefunden werden müssen, wenn sie auch in den bis jetzt bekannten Thatsachen noch nicht enthalten sein sollten."

This assumption of *Weismann* of a reduction of chromatic elements in the second polar body in the eggs of *Ascaris* and in general, is now in a wonderful way proved by *O. Hertwig*,[12] whose beautiful monograph has given me so much pleasure that I have read it over and over again, the more so, since his results are in exact parallelism with those obtained by myself in studying the sexual cells of *Diaptomus*, as stated above.

Thus the observations of *Platner*,[17,18] *Hertwig*[12] and myself show clearly that there is a kind of nuclear division in the formation of the second polar body as well as in the last cell division in spermatogenesis which is quite different from the ordinary karyokinesis, and which takes place in perfect accordance with *Weismann's* views.

Boveri also sees the necessity of admitting the "Reduktionstheilung" at each ontogenetic stage, but he lets this take place not in the formation of the polar bodies, but before it. On page 62 of his "Zellen Studien, Heft 3," he says:—

"Wann die reduzierte Chromosomenzahl zuerst auftritt und wie die Reduktion zustande kommt, dafür besitzen wir noch sehr wenige Anhaltspunkte. Betrachten wir zunächst die Eibildung, so können wir nur den *einen* Satz als sicher und allgemein gültig aufstellen, dass die Reduktion *spätestens im Keimbläschen* erfolgen muss. Denn bei der Bildung der ersten Richtungsspindel kommen die Chro-

mosomen bereits in der reduzierten Zahl zum Vorschein. Falls also *Weismann* seine theoretische postulierte Reduktion der Zahl der Ahnenplasmen mit dieser thatsächlichen Reduktion der Zahl der Chromosomen identifizieren will—was nicht nothwendig ist—so muss er die Annahme, dass dieselbe durch die Bildung des zweiten Richtungskörpers vermittelt werde, aufgeben."

But as the observations of *Boveri* on this point in *Ascaris* were proved not to hold true by the above cited investigation of *Hertwig*, I will not treat of it again here, but will only refer the reader to his beautiful monograph.

The latest series of observations come from *Haecker*[8] and *Henking*,[9,10] both of whom also admit the introduction of a reduction of chromatic elements at the beginning of each embryogenesis. They admit, however, this to take place in the formation of the first polar body and not in that of the second. *Haecker* who studied the formation of the polar bodies in *Cyclops* gives a couple of very fine woodcuts, which lead one to think that the "Reduktionstheilung" takes place in the formation of the first polar body. As in the case of *Diaptomus*, the chromosomes in the sexual cells of *Cyclops* number eight. These divide longitudinally in stage A, and produce sixteen elements, every two of which lie close together and thus form eight groups of double elements. In stage B, they become separated into two groups each of four double elements, one of which serves for the formation of the first polar body. The remaining four double elements now arrange themselves to form the second polar spindle (stages C and D). *Haecker*, however, quite rightly does not regard his observations as to the stages in which the "Reduktionstheilung" takes place as conclusive. After discussing the possibility of *Boveri's* discoveries in eggs of *Tiana*, *Echinus*, *Carinaria*, *Pterotrachea*, and *Phyllirrhoi* being in accordance with his own view, *i.e.*, that the "Reduktionstheilung" takes place

during the formation of the polar bodies, he concludes :—

"Die Reduktion findet also während der Ausstossung der Richtungskörper statt und es fragt sich nunmehr, welches Stadium im Speciellen die Reduktion darstellt.

"Die nächstliegende Deutung der Verhältnisse wird wohl folgende sein : die Längsspaltung der Chromosomen im Stadium A ist gewissermassen eine anachronistische, d. h. die normalerweise in der Aequatorialplatte der *zweiten* Richtungsspindel stattfindende Längsspaltung der Chromosomen, in gewöhnlichen Fällen also die secundäre, wurde in die Aequatorialplatte der *ersten* Spindel zurückverlegt, ein Vorgang, der nach Boveri's Befunden nichts Auffälliges bietet. Sieht man also ab von dieser (secundären) Längsspaltung, so übernimmt die erste Spindel aus dem Keimbläschen die ursprüngliche, nicht reducierte *Achtzahl* der Elemente, um von diesen durch einen besonderen Vertheilungsprocess vier in den ersten Richtungskörper, vier in den Eikern abzuscheiden, ohne dass die primäre Verdoppelung der Schleifenzahl, wie sie sonst der ersten Spindel zukommt, auftritt. Nach dieser Deutung fände also die Reduktion bei der Ausstossung des *ersten* Richtungskörpers statt.

"Man kann aber den Thatsachen noch eine andere Deutung geben : die Spaltung der acht Chromosomen in *Doppelfäden* würde der primären Längsspaltung der Elemente entsprechen. Auch diese Deutung schliesst einen abweichenden Theilungsvorgang schon in der *ersten* Spindel in sich : anstatt dass jeder Pol von jedem Doppelfaden je *ein* Tochterelement an sich zieht, findet nach jeder Seite die Abscheidung *von vier Paaren* von Tochterelementen statt. Die vier im Ei zurückgebliebenen Paare liefern dann die acht einfachen Elemente, welche in der *zweiten* Spindel *zu je vieren* nach den Polen derselben attrahiert werden. Diese Deutung würde die eigentliche Reduktion *also erst in die zweiten Spindel verlegen.*"

Thus while *Hœcker* allows the probability of the occurrence of a "Reduktionstheilung" in the formation of either the first or the second polar body, *Henking* is quite decidedly of the opinion that this division takes place in the formation of the first polar body. In his latest work on *Pyrrhocoris apterus*, *L.* he gives a detailed description of the formation of spermatic elements and polar bodies, in which he says[10,11]:—

"1) Den Ursamenzellen entsprechen die Ureier. Beide Zellformen enthalten die für die Körperzellen charakteristische Zahl von 24 Chromosomen.

"2) Den unreifen Eiern entsprechen die Samenmutterzellen (Spermatocyten I. Ordn.). Beide wachsen erheblich heran, in beiden kommt es zur Ausbildung eines verhältnissmässig grossen bläschenförmigen Kernes, in beiden werden Dotterkügelchen erzeugt.

"3) Die Abschnürung des ersten Richtungskörperchens entspricht der ersten Theilung der Spermatocyten. In beiden Fällen kommt es zu einer (Weismann'sche) Reduktionstheilung, indem sich die Chromosomen „zwei reichig" aufstellen und zu je 12 Elementen in die neuen Zellen übergehen. Die typische Zahl 24 wird also hier durch einfache Trennung der chromatischen Elemente auf 12 reduciert.

"4) Die Ausbildung des zweiten Richtungskörpers entspricht der zweiten Theilung der Spermatocyten. Die 12 chromatischen Elemente werden unter Beibehaltung der Zahl durch Aequationstheilung direkt halbirt, ohne dass sich das Stadium eines ruhenden Kernes dazwischen einstellte. Die sofortige Theilung der Spermatocyten II. Ordn. wurde möglich, weil die vorhergehende erste Theilung nicht als normal anzusehen ist und weil die letztere wahrscheinlich bewirkte, dass sich gleich die auch für eine zweite Theilung nöthige (also doppelte) Zahl chromatischer Fäden an die Chromosomen anheftete."

Henking tries also to make his observations coincide with those

of *Hertwig* upon *Ascaris* by giving different interpretations to the results obtained by the latter investigator. Whatever may be the interpretation in the case of *Ascaris*, my own case, given above, can not to my mind be made to coincide with his observation on *Pyrrhocoris*. I will not, however, assert the "Reduktionstheilung" in the formation of the second polar body and in the last cell division in the spermatogenesis to be the universal rule until a sufficient number of observations be obtained in other groups of animals and perhaps of plants too. Theoretical considerations concerning the phenomena of fertilization lead us in all probability to the "Reduktionstheilung" as occurring in the second polar body and in the last division of spermatic cells.

I will now consider very shortly the phenomena of fertilization. As stated above, the maternal and paternal nuclei do not unite into a single segmentation nucleus, as *Hertwig*[12] for the first time gives out, but remain separate from each other till after the complete formation of the segmentation spindle. Something of the kind had been already observed by various writers, but this fact was brought out in its full light only by the last work of *Ed. van Beneden* and *Julin* [1] on *Ascaris*. In the eggs of a copepod crustacea *(Cetochilus) Grobben*[8] observed for the first time, that the two nuclei do not become united with one another and form a single segmentation nucleus, but "stossen die beiden Kerne, Eikern und Spermakern, aneinander und sind nur noch durch eine zarte Wand voneinander geschieden. Auf dieses Stadium folgt sogleich die Bildung der ersten Kernspindel." But above all, the recent valuable investigations of *Boveri*[5] on this head in various groups of animals, as well as his enumeration of facts obtained by previous workers, make us accept this as the rule, and the perfect union of both the nuclei as exceptional cases only. To these we may add the observations of *Henking*[11] on the eggs of *Pieris*, as well as that of *Hœcker*[9] on *Cyclops*. My own observation on the

conjugation of *Noctiluca*[14] can also be looked upon as a further contribution in this line.

Science College, End of May, 1891.

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Explanation of the Plate.

Diaptomus sp.?

Fig. 1.—Longitudinal section of a testis: the lower end represents the formative zone and the upper end is the place where the vas deferens takes its origin. 1/III × Seibert = 120.

Fig. 2.—The formative zone of the testis represented by fig. 1. more highly magnified. A karyokinetic figure at the right is drawn here from the corresponding part of another animal. 1/VII × Seibert = 850.

Figs. 3–5.—Represent successive stages after the last division of the cells in the formative zone. 1/VII × Seibert = 850.

Figs. 6–8.—Cells from the formative zone. In figs. 6 & 7 the eight chromosomes are still long and are difficult to count. In fig. 8 the chromosomes are much shortened in the cell on the right hand side. 1/VII × Seibert = 850.

Figs. 9, 10, & 11.—Show the first division of the sperm-mother cell. Fig. 9 is drawn from a specimen killed with picro-acetic acid, and coloured with hæmatoxylin. Three of the eight dumb-bell shaped chromosomes are seen on this side and five others on the other side. Figs. 10 and 11 are specimens killed with methyl-green-acetic acid. In both figures the eight chromosomes lie on the periphery of a circle and in both of them five elements lie on one side and the three others on the other. All drawn by Seibert 1/VII and magnified 850 times.

Figs. 12–16.—Show the second division of sperm-mother cells immediately following the last division without an intermediate resting

stage. Figs. 12 & 14 show a stage just after the first division : eight single chromosomes are still in a single plane. Fig. 13 is the polar view of the same. Fig. 16 represents a stage a little more advanced than those of figs. 12 & 13. in which eight chromosomes lie in two circles of four each. Fig. 15 is more advanced and the cell itself has now begun to divide. Figs. 12–15 are drawn from specimens killed with picro-acetic acid, and fig. 16 with acetic acid methyl-green. All drawn by 1/VII Seibert = 850.

Figs. 17–22.—Last changes in the formation of spermatozoa. Fig. 17 is just after the second division of the sperm-mother cell. The nucleus is now found to stain homogeneously. In fig. 18 a cell on the left shows a vacuole in the nucleus ; in the other two cells, as well as in that of fig. 19, traces of chromosomes are more or less distinctly to be seen. Fig. 20 shows two cells in which a big vacuole appears. In fig. 21 chromatic elements have become more distinct than in figs. 18 (two cells on the right) and 19 : the nuclear membrane has become more or less indistinct. Fig. 22 represents four spermatozoa found in the vas deferens. All drawn by 1/VII × Seibert = 850.

Figs. 23 & 24.—Represent the posterior ends of two ovaries. In fig. 24 the extreme end is not represented. Both drawn by Seibert 1/V = 33.

Fig. 25.—Two eggs just before the formation of the first polar body. In both of them are seen eight dumb-bell shaped chromosomes scattered rather irregularly in the germinal vesicle. In the germinal vesicle of the egg on the left, a nucleolus and a number of small circular bodies—the micro-nucleoli—are seen, while in that of the egg on the right the nucleolus is no more to be seen. This figure is compiled from three successive sections. 1/V × Seibert = 330.

Figs. 26–29.—First polar spindles. Figs. 26, 28, and 29 represent the side view and fig. 27 the polar view. The nuclear membrane

has already disappeared and the eight chromosomes lie in a ring. Figs. 26–28 were treated with hot-alcohol-sublimate and the achromatic fibres are not to be seen. In fig. 29 the achromatic fibres are well represented. All drawn with Seibert 1/VII=850.

Fig. 30.—A small superficial portion of an egg, just after the formation of the first polar body, and the second polar spindle is seen from a pole. Eight short chromatic elements are seen in a plane at the equator of the spindle which is not represented in the figure. Seibert 1/VII=850.

Figs. 31, 32, & 33.—Represent three sections in which the second polar spindle and a spermatic nucleus are present in the egg, and in relatively different positions. In all the spindles the four chromosomes are more or less distinctly to be seen. Figs. 31 and 32 are drawn by Seibert 1/V=330 times, and fig. 33 by Seibert 1/VII=850 times.

Figs. 34 & 35.—Division of the second polar spindle is nearly complete, and the egg-nucleus has swollen up a little. The four chromosomes are now more or less elongated. Both drawn with Seibert 1/VII = 850.

Fig. 36.—Piece of an egg in which the second polar body, the egg nucleus, and the spermatic nucleus are present. The four chromosomes in the egg-nucleus are much elongated and are joined together by "Linin fäden." The spermatic nucleus is now much larger than the egg-nucleus. Seibert 1/VII=850.

Fig. 37.—The copulating nuclei out of an egg, the larger of which represents the spermatic and the smaller the egg nucleus. At one pole of the egg-nucleus is seen a small central body with an "archoplasma" around it. Seibert 1/VII=850.

Figs. 38–55.—Represent various stages of copulation and the first segmentation spindle of an egg. In fig. 38 is seen the second polar body at the left hand upper corner. The two nuclei are approaching

one another. Near the smaller one—the egg-nucleus—is seen two centrosomes not widely separated from each other. In fig. 39 the nuclei are much larger and the central bodies now lie between them. In fig. 40 the section did not pass exactly in the plane of both nuclei, which therefore are seen as overlapping one another. These three figures are drawn from specimens killed with picro-acetic acid solution. Figs. 41–45 are drawn from specimens killed with Flemming's solution. In fig. 41, the first polar body is by chance seen lying outside the egg-membrane. Figs. 46–55 are drawn from specimens killed with hot-sublimate-alcohol. In figs. 46 and 47 the two nuclei have still a distinct membrane. In both of them we see eight chromosomes. The sizes of the nuclei are still a little different from one another. In fig. 48 the nuclear membranes have become somewhat indistinct, and the nuclei themselves are more or less drawn by the attraction spheres. The relative positions of the latter and the nuclei are very interesting in regard to the manner in which the nuclei are drawn by the attraction spheres. In fig. 49 the two nuclei are drawn equally by the attraction spheres, and the chromatic elements lie at the equator of the spindle. Fig. 50 represents a transverse section of such a spindle. In fig. 51 the nuclear membranes have disappeared completely, but the chromatic elements of both the nuclei are still lying separated from one another. Fig. 52 represents a transverse section of such a spindle more highly magnified. In fig. 53 and 54 the two groups of chromosomes are no longer distinct from one another. Lastly in fig. 55 the chromosomes have just begun to separate from the equatorial plane into two new groups, each consisting of eight elements. All these figures are drawn with Seibert $^1/_V = 330$, with the exception of Figs. 52 and 55 which are drawn with Seibert $^1/_{VII} = 850$.

Further Studies on the Formation of the Germinal Layers in Chelonia.

(Contributions to the Embryology of Reptilia III).

By

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With Plates II.—IV.

Some years ago conjointly with Mr. Ishikawa, I published a paper *on the Formation of the Germinal Layers in Chelonia (No. 1).* Our observations were then made solely on Trionyx japonicus, *Schlegel.* Recently I have had an opportunity of studying the earlier stages in the development of Clemmys japonica, *Gray.* The results of my observations in the latter species confirm our views on all essential points. In addition, I have been able to elucidate more fully the earlier phases in the formation of the mesoblast not only in Clemmys but also in Trionyx. These, in my opinion, lead to conclusions of considerable importance and deserve the attention of those who are engaged in the study of the vertebrate development.

The materials for the investigation were as before obtained from tortoises which breed freely in captivity. As each deposit of eggs was marked as it was laid, I had an unusual opportunity of obtaining a complete series of embryos. In some cases, I took eggs out of one deposit at several different times, in order to determine more ac-

curately the succession of the changes that take place.

On the present occasion, I shall not touch on the formation of the mesoblast or mesenchyma at the periphery of the blastoderm an account of which, I reserve for a future paper.

Clemmys japonica, *Gray.*

The earliest stage in my possession was obtained from the eggs opened directly after they were deposited. The blastodermic region, owing to its lighter specific gravity, is always found at the upper pole, in whatever position an egg may happen to have been deposited. Surface views of the blastoderm are represented in Figs. 1 and 1a (Pl. II). It corresponds to that shown in Figs. 1a and 1b of the paper on Trionyx (No. 1) but is somewhat younger. The blastoderm shows a comparatively large pellucid area, in which the embryonic shield is placed excentrically, nearer its posterior edge, and is joined to this edge by irregular opaque patches. The most conspicuous feature in the dorsal view of the embryonic shield (Fig. 1) is the dorsal opening of the blastoporic passage. It is placed in the median line near the posterior end of the shield, and is a crescent-shaped, transverse slit, the concavity being to the front. The embryonic shield shows indistinctly two concentric zones which are most marked in front and at the sides. The innermost area is the most opaque part of the blastoderm. Near the front edge of this area, there is however a somewhat less opaque area which corresponds, it will be seen, on referring to the ventral view (Fig. 1a), to the ventral opening of the blastoporic passage. In the same view (Fig. 1a), the innermost and most opaque area is seen to be the thick part through which the blastoporic passage leads from the dorsal to the ventral opening.

The minute structure of this early stage will become clear from

a study of Figs. 5 and 5a (Pl. III, a longitudinal section) and Figs. 6–10 (a series of transverse sections).

Fig. 5 is a longitudinal section of this stage, near the median line. The blastoporic passage is very conspicuous, beginning at the dorsal surface and leading obliquely forwards to the ventral surface. There is a marked difference of structure between the part of the blastoderm in front of the passage and that lying behind it. In front of the passage, there are only two layers : the epiblast and the primitive hypoblast. The epiblast is already a well defined sheet, extending beyond the area included in the figure—though how much beyond I have not ascertained. In the transparent area in front, it is a thin layer consisting of pavement cells ; as we trace it posteriorly however, the cells become taller, changing gradually from the pavement to the columnar shape. In the region directly in front of the dorsal opening of the blastoporic passage, the nuclei are in several strata, although the epiblast seems to consist in reality of only a single layer of tall cells. As regards the lower layer or primitive hypoblast, it is, in the anterior transparent area, a loose layer of cells containing many fine yolk-granules (Compare Trionyx No. 1, Fig. 15). In front it passes into the bed of yolk in which nuclei are seen. Traced backwards, it becomes at first only two or three cells deep, and then suddenly quite thick as we reach the outer of the two concentric zones seen in the surface view of the embryonic shield. The cells here are arranged in a loose network, with large meshes. Further backwards, the lower layer is formed of columnar cells and assumes an appearance like the superjacent epiblast. It is thicker, however, and seems to be formed of several layers of cells. At the anterior dorsal lip of the blastoporic passage, the epiblast becomes continuous with the primitive hypoblast.

In that part of Fig. 5 (or Fig. 5a) showing the region behind the blastoporic passage, there is a different state of things. Beginning

at the hindmost part, the epiblast is already formed as far back as is given in the figure. As we trace it forward, it is distinct up to the blastoporic passage, but here it becomes merged in a large thick mass of cells which stretches along the floor of that passage. The lower layer, which is continuous behind with the yolk-bed and which is distinguished by containing a larger quantity of yolk granules, is also joined to the large mass on the floor of the blastoporic passage by irregular reticulate strands of cells. Thus, behind the blastoporic passage the layers are fused together, and there can be no doubt that the thick mass of cells is the beginning of what Rabl calls the peristomal mesoblast.* Eventually it will stretch backward for the space of 180° like an open fan, between the epiblast and the definitive hypoblast.

Figs. 6–10 are a series of cross-sections from another embryo in the same stage, arranged from behind forward. They confirm what we have learned from the longitudinal section and give us some additional information.

In Fig. 6, taken from directly behind the blastoporic passage, the epiblast is marked by a groove at about the median line, and is at this point proliferating downwards cells which form a small mass continuous with the lower layer by loose strands of the cells. This proliferation is seen more or less distinctly in several consecutive sections until it joins in front the large mass on the floor of the blastoporic passage. This median line of proliferation I take to be the commencing primitive streak. This becomes broader and more conspicuous in later stages. The same thing was seen in Trionyx (*loc. cit.*, Figs. 6 and 8).

In Fig. 7, the epiblast is no longer distinguishable in the median region, which is occupied by the solid thick mass of cells already

* C. Rabl:—Theorie des Mesoderms. Morph. Jahrbuch, 1889.

noticed in the longitudinal section. There becomes established later on at this place the yolk plug, as reference to Fig. 22 will show, and as has been proved sufficiently, I think, in the case of Trionyx (*loc. cit.*).

In Fig. 8, the section passes through the blastoporic passage which is, however, still open above on the left. The floor of the passage is proliferating cells below.

In Fig. 9, through the front part of the ventral opening of the blastoporic passage, the cells of the lower layer are arranged in the median line in a regular columnar epithelium. This is what is usually known as the chorda-hypoblast, although, as I shall show in the sequel, it gives rise to something besides the chorda dorsalis. Laterally the chorda-hypoblast becomes continuous with loose irregular reticulate masses of lower-layer cells containing a large quantity of yolk granules. Still more laterally the lower layer is reduced to a very thin sheet corresponding to the transparent region of the surface view. Outside of this it becomes continuous with the bed of yolk-matter.

As we trace the series of sections forward, the part of the lower layer showing a regular columnar arrangement becomes smaller and smaller, the loose network-like part encroaching gradually on it. Columnar cells remain longest on the lowest stratum of the median part (Compare Trionyx, *loc. cit.*, Figs 13 and 14).

In Fig. 10, the whole lower layer in the region of the embryonic shield consists of a loose network of cells.

This embryo thus consists almost entirely of only two layers, the epiblast and the primitive hypoblast. The only part which we can distinguish as the commencing mesoblast is a median mass of cells found behind, and on the floor of, the blastoporic passage, continuous above and below with the two primary layers. In front of the blastoporic passage, the chorda-hypoblast is being gradually arranged in

the median line in the form of a regular columnar epithelium from cells forming the loose network of the primitive hypoblast. The process proceeds from behind forward. This embryo thus closely agrees with the first stage of Trionyx, which we described in our former paper.

Formation of the Mesoblast.

How does the embryo described above change into one in which the three germinal layers are completely and definitely established? As stated in the account of the formation of the mesoblast given in our paper on Trionyx, the process is briefly this: as the forward continuations of the peristomal mesoblast whose commencement we saw in the above stage, a pair of mesoblastic bands become gradually established, one on each side of the median chorda-hypoblast, between it and the gut-hypoblast (=*Darm-Entoblast*). This is the gastral mesoblast of Rabl. From my study of Clemmys, I am now in a position to give more exact details in regard to the first stages in the formation of this gastral mesoblast, and as will now appear I have to qualify somewhat my views of these earliest stages. This is necessitated by the discovery I have made concerning the chorda-hypoblast. I find that in Chelonia at least, only the median part of what I have hitherto called the chorda-hypoblast gives rise to the chorda dorsalis, and that each side of it becomes eventually incorporated in the mesoblast. Thus, in Fig. 11, from an embryo somewhat older than that represented in Fig. 1, the median unshaded portion alone becomes the chorda dorsalis, while the shaded lateral parts form in the sequel part of the mesoblast.

As this is a very important point, I shall try to prove it before

proceeding further, from observations which in my opinion make the above conclusion inevitable.

I wish to call attention first to Fig. 23 (Pl. IV.), from the head region of a somewhat old embryo given in Figs. 4 and 4*a*. Here the gut-hypoblast (or *Darm-Entoblast*), instead of joining the chorda-hypoblast, turns upwards and becomes continuous with the mesoblastic mass. The chorda-hypoblast in immediate continuation of the chorda also turns upwards and becomes merged in the mesoblastic mass. Between the chorda-, and gut-, hypoblast, a diverticulum of the archenteron enters into the mesoblastic mass on each side of the chorda. Now it seems to me that this section can have but one interpretation, and represents, as clearly as we can reasonably expect in a meroblastic egg, the process of the mesoblast development so well known in Amphioxus. Here, however, from the outer and upper walls of the diverticulum (I am speaking more especially of the left side of the section), a mass of cells stretches outward. That this mass has budded out from the walls of the diverticulum is evident from the karyokinetic figures which we see in it. This section ought therefore, strictly speaking, to be compared to such a section of Amphioxus as is given in Fig. 40 (Pl. IV.), in which the mesoblast has stretched more ventrally. To make the comparison yet closer, the gut would have to be still in open communication with the coelom in the section of Amphioxus. Now, when the chorda, the mesoblast and the gut-hypoblast finally separate from one another in Clemmys, at what point does this separation take place? In order to answer this question conclusively, I have introduced Figs. 33–36 from the head region of another embryo of about the same stage. Fig. 33 is essentially like Fig. 23. The right side of this section is more forward than the left side and is significant, for the gut-diverticulum is quite simple, and there has not yet been as much pro-

liferation of mesoblast cells from its walls as on the left side or in Fig. 23. But the point that I want to be particularly noticed in the section is on the left side which, as I said before, is essentially like the corresponding side of Fig. 23. Two sections behind this (Fig. 34), the hypoblast has pushed towards the median line and obliterated the gut diverticulum, of which, however, its outer and inner walls are as yet distinguishable. Fig. 35 is two sections still further behind, where the parts are pressed closely together. Two or three sections yet further back, the chorda, the gut-hypoblast, and the mesoblast have entirely separated from one another (Fig. 36). This series shows conclusively that the part of the primitive hypoblast immediately adjoining the chorda becomes a part of the mesoblast.

Now turn to Fig. 12 (Pl. III), taken from the head region of the embryo shown in Figs. 3 and 3*a*, somewhat younger than that of Fig. 4, from which Fig. 23 is taken. In this section, between the chorda-*anlage* and the gut-hypoblast, there is a stretch of columnar epithelium slightly arched upwards. From the point where this epithelium joins the gut-hypoblast, there stretches outwards a mass of mesoblast cells between the epiblast and hypoblast. Now there can be no reasonable doubt that this section presents substantially the same structure as the left side of Fig. 23. If the epiblast did not press down so closely, and if the epithelium (lightly shaded in the figure) between the points marked with † and * arched upwards with a greater curvature, the section would be exactly like the left side of Fig. 23. We therefore come to the conclusion, that the epithelium (lightly shaded in Fig. 12), stretching between the chorda-*anlage* and the gut-hypoblast, and continuous with both, ought to be considered as the walls of the gut-diverticulum, and a slight bay between † and * as representing the gut-diverticulum itself. From the outer walls of this diverticulum,

the mass of mesoblast cells (darkly shaded in the figure) are stretching outwards. This section again reminds us of the section of Amphioxus shown in Fig. 40.

I wish to call attention next to the embryo represented in Fig. 2. This is interesting, because the gastral mesoblast in extending itself forwards from the peristomal mesoblast has not yet reached the anterior end of the embryonic shield, where there is as yet no head-fold, and we are thus able to see in what manner this forward extension takes place. Figs. 13–22 are sections of this embryo. If we look at Fig. 16 from the anterior part, we at once recognize its similarity to Fig. 12. There is the epithelium stretching between the chorda-*anlage* and the gut-hypoblast, and representing the walls of the gut diverticulum. From the outer end of this epithelium there stretches outwards the mesoblastic mass (darkly shaded). We see here as well as in Fig. 12 a very clear indication, (1) that the mesoblastic mass is divided into two layers: the somatopleuric and the splanchnopleuric, and (2) that the former is continuous with the above mentioned epithelium and the latter with the gut-hypoblast. The latter fact necessitates the conclusion that the gut diverticulum in extending itself into the proliferated mesoblast mass does so from its outer end.

When the chorda, the mesoblast, and the gut-hypoblast become independent of one another, at what point does the separation take place? In tracing the series backwards, we pass suddenly from sections like Fig. 16 to others like Fig. 17. This point corresponds in the ventral view (Fig. 2) probably with the place where the two converging depressions come together and form the single median groove. The change is brought about by the gut-hypoblast extending itself close to the chorda-*anlage*, thus shutting off the gut diverticulum from the enteric cavity. In other words, the point marked * in Fig. 16 has moved itself to the point marked †. In Fig. 17 the splanchnic

mesoblast is still continuous with the gut-hypoblast. This inward extension of the gut-hypoblast seems to be the signal for the separation of the three structures above mentioned, for very soon we come to sections like Fig. 18, in which the chorda-*anlage*, the mesoblast, and the gut-hypoblast have separated from one another. From this, it is evident that the epithelium lying between the chorda-anlage and the gut-hypoblast (the lightly shaded part in Fig. 16) and representing the walls of the gut-diverticulum, becomes a part of the mesoblast.—the same conclusion as was reached in the case of Fig. 23.

If we now trace the series forwards from Fig. 16 we find the proliferated mesoblast mass (darkly shaded in the figures) growing smaller and smaller (Figs. 15 and 14). A few sections forward, we come to the appearances depicted in Fig. 13. In this, we find laterally the gut-hypoblast consisting more or less clearly of a single layer of columnar cells. As we advance towards the median line, this epithelium suddenly stops at some distance from the chorda-*anlage*, and between it and the latter structure we find a stretch of epithelium with more than one layer of cells. This part I have shaded lightly in the figure. The increase of cell-strata in this part is possibly due to the fact that cells here are dividing rapidly to give rise to the mesoblast mass. The darkly shaded part (the proliferated mesoblast cells) in this figure ought therefore perhaps to have been extended further inwards.

Further forwards, the chorda-*anlage*, the mesoblast, and the gut-hypoblast are all as yet undifferentiated, and the lower layer consists of a single layer of columnar cells throughout.

It is evident from the foregoing description, that the lightly shaded part of Fig. 13 is equivalent to the similarly shaded part of Figs. 16 and 12, which in its turn is comparable to the walls of the

gut-diverticulum in Fig. 23, and that this part becomes eventually incorporated in the mesoblast. This obliges us to come to the conclusion that the median part of Figs. 9 and 11, which shows a regular epithelial arrangement—the part which I have hitherto called the chorda-hypoblast—does not give rise to the chorda alone but has potentially the elements of the mesoblast in it. I have tried to show what I mean by shading in Fig. 11. The median unshaded part is the part that gives rise to the chorda ; the lightly shaded stretch, immediately adjacent to it on each side, which corresponds to the similarly shaded part of Figs. 13–17, gives rise to the gastral mesoblast and becomes finally incorporated in the mesoblast. The section represented in Fig. 11 is therefore strictly comparable to the well-known section of Amphioxus reproduced in Fig. 39. According to this view, the apparently insignificant features : the bulging downwards of the chorda-*anlage*, and the slight bay on each side of this median projection receive their explanation.

I think, I have now sufficiently demonstrated the proposition I started with, viz: In Chelonia, at least, only the median part of what has hitherto been called the chorda-hypoblast gives rise to the chorda dorsalis while the lateral parts of it become eventually incorporated in the mesoblast.

I will now rapidly go over different stages and give a brief but connected history of the above occurrences, as well as of those points not yet touched upon.

I have already described in full the stage represented in Figs. 1 and 1*a*. It will be remembered that this embryo consists almost entirely of two layers, except in the region behind the blastoporic passage, where the peristomal mesoblast is beginning to form. This mesoblast

soon increases in bulk and spreads out behind in all directions like an open fan. From the two edges of this fan, the formation of the gastral mesoblast proceeds gradually forward (see Fig. 2 and its sections Figs. 13–22). It has sufficiently been shown above that a certain stretch of epithelium found on each side of the chorda-*anlage* in early embryos (like that given in Figs. 1 and 1*a*) becomes eventually a portion of the mesoblast. Only there is as yet nothing to distinguish it as such. While the remaining part (i.e. the gut-hypoblast) of the lower layer becomes gradually reduced to a single stratum of columnar cells, this stretch of epithelium distinguishes itself by proliferating cells which spread partly upwards, but mostly outwards between the epiblast and the gut-hypoblast (the embryo given in Fig. 2 and its sections Figs. 13–22). At this stage, therefore, the internal end of the gut-hypoblast on each side is at a considerable distance from the chorda-*anlage*. (Figs. 12 and 16). The gut-hypoblast, however, soon extends itself towards the chorda-*anlage*, shutting off the epithelial stretch in question from the enteric cavity (Fig. 17). This inward extension of the gut-hypoblast is probably the cause of the grooves converging posteriorly into the single median chorda groove seen in the surface views, Figs. 2 and 3*a*. This movement seems also to be the signal for the separation of the three structures: the chorda-*anlage*, the mesoblast, and the definitive or gut-hypoblast (Fig. 18). The separation is, however, complete only in the middle of the embryo, for, as we go backward and approach the blastoporic passage, the three structures are again united (Fig. 19 and 20). This is necessarily the case, I think, because the posterior part of the embryo is growing in length. In Fig. 22, we see that the yolk-plug has become very distinct. This has been brought about by the change of shape in the dorsal opening of the blastoporic passage. Whereas it is at first concave forwards as in Fig. 1, it becomes later horse-shoe shaped (see Figs. 3 and 4), with

the concavity turned backwards.

Of an older embryo (Figs. 4 and 4*a*) with the head-fold and the commencing amnion, a section from the head (Fig. 23) has already been sufficiently described. As we pass backward, we see that the cavity of the gut-diverticulum is obliterated (Fig. 24). A little further behind, three structures: the chorda-*anlage*, the mesoblast, and the gut or definitive hypoblast become separated after the manner shown in Figs. 33–36. We then obtain a section such as Fig. 25. In the middle region of the body, the formation of the chorda dorsalis is completed (Figs. 26 and 27) exactly in the way described in our Trionyx paper (No. 1). Further backwards, the definitive hypoblast of two sides which is united across in Fig. 27, separates again from each other (Fig. 28) and still more posteriorly, the three structures above mentioned become united once more (Figs. 29 and 30). Figs. 31 and 32 are so exactly like Figs. 21 and 22, or similar figures in Trionyx, that they need no special description here.

Trionyx Japonicus. *Schlegel*

After making out the earlier phases in the formation of the gastral mesoblast in Clemmys, I thought it necessary to reexamine Trionyx. I succeeded in finding two embryos in which the gastral mesoblast had not yet reached the anterior end and was in process of formation. After cutting them into sections, I found that they present exactly the same structures as the Clemmys embryo given in Fig. 2. In order to prove this point, I have selected and figured two sections (Figs. 37 and 38) from one of the embryos. In Fig. 37, the gut-hypoblast is at some distance from the median line, and there is a stretch of epithelium between it and the chorda-*anlage*, which is continuous externally with the proliferated mesoblast mass. Several sections behind, in Fig. 38, the gut-hypoblast has shifted its inner end to the chorda-*anlage*, and

the aforesaid stretch of epithelium has been cut off from the enteric cavity and incorporated with the mesoblast.

In a note published in the *Anatomischer Anzeiger*, No. 7, 1891 I called attention to the section given in Fig. 23 of the present paper, and Figs. 25 and 29 of our Trionyx paper, and pointed out that while both represented essentially the same structure, mesoblast cells in Trionyx were budded off as separate stellate cells, while those in Clemmys appeared as a more or less solid mass. I have now to qualify that statement. On referring to the original sections from which Figs. 25 and 29 of Trionyx were drawn, I find that they are very faithful representations. But in sections which I have obtained lately, I find that the cells appear aggregated in a loose mass, and are by no means so separate as in Figs. 25 and 29. This difference, I think, is due to difference in the fluid in which they were killed. The earlier embryos were treated with corrosive sublimate, while the later ones were all preserved in picro-sulphuric acid. I am now inclined to thinkt that, Trionyx and Clemmys are after all, not so unlike in this respect.

So far as I am aware, the facts described above in regard to the earlier phases in the formation of the gastral mesoblast are now brought out for the first time. It appears to me that they have considerable significance, for they make the process of the mesoblast formation in higher vertebrates agree with the same process in Amphioxus much more closely than we have hitherto been able to do. These facts have also, in my opinion, an important bearing in explaining the mesoblast formation in the chick. Fig. 100 in Balfour's *Comparative Embryology*, Vol. II. is substantially the same as Fig. 17 or 38 of the present paper. Balfour says :- -" From what has just been said, it is clear that in the region* of the embryo the mesoblast originates as two

* I. e. in front of the primitive streak.

lateral plates split off from the hypoblast, and that the notochord originates as a median plate, simultaneously with the mesoblast, with which it may sometimes be at first continuous." (*loc. cit.* p. 157. edition of 1885). Now suppose that the earlier phases of the mesoblast formation in Chelonia are very rapidly gone through or altogether skipped over, and the state represented in Figs. 17 and 38 is reached *per saltum:* we shall then necessarily obtain appearances which would make us conclude that the lateral plates of the mesoblast, or at least the part of it immediately adjacent to the chorda, becomes split off from the hypoblast. My contention then is that the process of the mesoblast formation in the chick is an extremely abbreviated form of the process described above in Clemmys or Trionyx. The question naturally arises whether cells are added on to the mesoblast from the gut-hypoblast, outside of the stretch of epithelium representing the walls of the gut-diverticulum. I wish to leave this question open at present: there are appearances which lead me to think so, but they are by no means conclusive. Theoretically, there should be no cells added outside of the gut-diverticulum.

SCIENCE COLLEGE, JUNE, 1891.

Contributions to the Embryology of Reptilia.

(No. 1.) I. On the Formation of the Germinal Layers in Chelonia. Quart. Jour. Micr. Sc., Vol. 27. Also reprinted in Jour. Sc. College, Tōkyō, Vol. I, pt. 3,

(No. 2.) II. On the Foetal Membranes of Chelonia. Jour. Sc. College, Tōkyō. Vol. IV., pt. 1,

Explanation of Figures.

Plate II.

Fig. 1.—Dorsal view of a Clemmys embryo taken out 1 hour after its deposition. Zeiss aa × 2. (XXXV)

Fig. 1a.—Ventral view of the same. aa × 2.

Fig. 2.—Ventral view of a Clemmys embryo 3 days old. aa × 2. (XXXVII).

Fig. 3.—Dorsal view of a Clemmys embryo 3 days old. aa × 2. (XXXVII).

Fig. 3a.—Ventral view of the same. The head-fold marks definitely the anterior end of the embryo. aa × 2.

Fig. 4.—Dorsal view of a Clemmys embryo 3 days old. aa × 2. (XXXVIII).

Fig. 4a.—Ventral view of a Clemmys embryo 3 days old, from the same deposit as Fig. 4. Note the two depressions, one on each side, immediately behind the head-fold and partly covered by it. These depressions are the diverticula of the enteric cavity seen in Fig. 23. aa × 2.

Plate III.

Fig. 5.—Longitudinal section of the Clemmys embryo represented in Figs 1 and 1*a* near the median ventral line. BB × 2.

Fig. 5a.—Part of Fig. 5 more highly magnified. DD × 2.

Fig. 6-10.—Selected transverse sections from a Clemmys embryo from the same deposit and of the same stage as Fig. 1. BB × 4. (XXXV*a*).

Fig. 6.—From directly behind the dorsal opening of the blastoporic passage.

Fig. 7.—Still nearer the dorsal opening of the blastoporic passage.

Fig. 8.—Through the blastoporic passage.

Fig. 9.—Anterior to the ventral opening of the blastoporic passage.

Fig. 10.—Through the anterior part of the embryonic shield.

Fig. 11.—Transverse section somewhat in front of the ventral opening of the blastoporic passage. From a Clemmys embryo a little more advanced than Fig. 1. This is introduced to show the destiny of different parts of the lower layer (or primitive hypoblast): the median unshaded part becomes eventually the notochord, the lightly shaded part on each side immediately outside the

chorda-*anlage* gets incorporated in the mesoblast, and the parts external to these shaded portions become the gut or definitive hypoblast. This should be compared with the section of Amphioxus reproduced in Fig. 39. BB × 4.

Fig. 12. Transverse section from the anterior part of the Clemmys embryo represented in Figs. 3 and 4*a*. DD × 2.

Figs. 13-22. Selected transverse sections from the Clemmys embryo given in Fig. 2. DD × 2.

Figs. 13-16.—From the anterior part, show the manner in which the gastral mesoblast extends itself forwards. The gut-hypoblast is at a considerable distance from the chorda-*anlage*. The lightly shaded part is the part of the original primitive hypoblast that becomes incorporated in the mesoblast. The darkly shaded part represents the mesoblast mass which has been budded out from the lightly shaded part.

Fig. 17.—The gut-hypoblast has extended itself inwards to the chorda-*anlage*.

Fig. 18.—A little behind Fig. 17. The chorda, the mesoblast and the gut-hypoblast have separated from one another.

Fig. 19.—Further behind. The three structures have again united.

Fig. 20.—Directly in front of the ventral opening of the blastoporic passage.

Fig. 21.—Through the blastoporic passage.

Fig. 22.—Through the yolk-plug.

Plate IV.

Figs. 23-32.—Selected transverse sections from the Clemmys embryo given in Figs. 4 and 4*a*. DD × 2.

Fig. 23.—Through the head region and the gut-diverticula. See the ventral surface view, Fig. 4*a*.

Fig. 24.—Third section behind.

Figs. 25-28.—From the middle region of the body, showing the formation of the notochord.

Figs. 29 & 30.—In front of the ventral opening of the blastoporic passage The chorda-*anlage*, the mesoblast, and the gut-hypoblast have again united with one another.

Fig. 31.—Through the blastoporic passage.

Fig. 32.—Directly behind the dosal opening of the blastoporic passage.

Figs. 33-36.—Selected transverse sections from the anterior part of a Clemmys embryo very similar to Fig. 4 and from the same deposit. Introduced to show the manner of separation of the three structures: the notochord, the mesoblast and the gut-hypoblast. Fig. 33, BB × 4, Figs. 34-36, DD × 2. (XXXXVIII).

Fig. 33.—Through the head-fold.

Fig. 34.—Second section behind.

Fig. 35.—Second section behind.

Fig. 36.—Fifth section behind.

Figs. 37-38.—Two transverse sections from a Trionyx embryo $1^1/_2$ days old. DD × 2. (127).

Fig. 37.—Is more forward. The gut-hypoblast is at some distance from the chorda-*anlage* and the median line.

Fig. 38.—The gut-hypoblast has extended itself inwards to the chorda-*anlage*.

Figs. 39-40.—Sections of Amphioxus. From Hatschek, after Hertwig.

On the Development of Limulus Longispina.

By

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With Plates V—XI.

After working out a general outline of the development of spiders,* I undertook the study of the development of the *Limulus* of this country with the object of ascertaining, if possible, how it is related to the Arachnida. In order to collect materials for this investigation, I was enabled, by the liberality of the University authorities, to visit Ajino in the province of Bizen, in the summer of 1889, and again in the same season of 1890. In that place, I had exceptional opportunities of collecting and observing the eggs of *Limulus*, by the kind assistance of Mr. B. Nozaki and Mr. T. Nozaki to whom my best thanks are due.

Limulus longispina is generally known by the name of *kabutogani*, but there are many local names such as *umidongame*, *mangoyei*, *hachigani*, *unkyū*, etc. In Bronn's "Die Classen und Ordnungen des Thierreichs" we find it stated that the Chinese call their *Limulus* as *Umi-dogame* or *Unkiie*; but this is evidently a mistake, these terms being a corruption of the Japanese names, *umidongame* and *unkyū*.

* Kishinouye—*On the Development of Araneina.* This Journal, vol. IV. Part I.

Of the spawning of the American *Limulus* there is a minute description by Lockwood in the *American Naturalist* vol. IV ; but as the spawning process of the Japanese *Limulus* differs a little from that of the American species, I shall give a brief account of it.

The *kabutogani* deposits its eggs chiefly in August. On calm nights during that month, males and females, the former on the abdominal shield of the latter, come in with the rising tide towards sandy shores. Judging from appearances after deposition, the process of spawning is as follows : Egg-laying takes place between the tide-marks, but only as this space becomes covered with water. The female excavates a hole, about 15 c.m. deep, and deposits eggs in it, while the male fertilizes them. The female afterwards buries them and begins to excavate the next hole. This process is repeated many times.

As *Limulus* can not dig deeper than about 15 cm. when the diameter of the hole is less than the breadth of the cephalothorax, the eggs deposited in such holes are liable to be washed out of the sand, and carried away by waves, when the wind is rather strong. This is especially the case with older eggs the vicarious chorion of which being inflated acts as a sort of float.

As a general thing, fishermen do not pay much attention to the *kabutogani* on account of its small economic value, and even an experienced fisherman does not know the place where it spawns. Such being the case, Mr. T. Nozaki kindly detailed a fisherman to make special search for the *kabutogani's* eggs along the shores of the Inland Sea. The fisherman succeeded in finding spawn of the animal on the shore at Obatake, a village not far from Ajino. I was taken by the fisherman and Mr. Nozaki to this spot. When we reached the place, the fisherman began to dig at random those parts of the shore, from which the tide had retired.

While I was looking about, my attention was caught by peculiar markings on the shore, such as are represented in fig. 1. On a close examination these markings proved to be the tracks of the spawning *kabutogani*. They consisted of a number of small roundish elevations (about 35 cm. in diameter) stretching in a line, which is always perpendicular to the coast-line and never parallel with it. The length of the line is $1\frac{1}{2}$–4 m.

The elevations are highest at one extremity and become gradually lower towards the other. The higher end is the spot where the *kabutogani* began egg-laying. Near the end of spawning, the legs of the female animal are no doubt tired, so that she cannot cover eggs with as much sand as at the beginning of the operation. The lower end of the spawn is often lost in scratches from legs, which show that the direction of movement has been from the higher to the lower end. The higher end may be either near to or away from the shore. From this fact we may conclude that the *kabutogani* in depositing eggs proceeds either towards or away from the shore. The latter will probably be the case when the spawning begins at the time of the receding tide, and the former when it begins at the time of the rising tide.

Under each elevation of the spawn there are about one thousand eggs aggregated and compressed together into a mass. The mass of eggs is not placed just under the centre of each elevation, but is deposited either to the left or to the right side of the median line of the whole spawn. On digging out one whole series of a spawn, I observed that in the higher half of it the egg-mass deviated towards the left side, and in the lower half towards the right side. From this I concluded that in this case the *kabutogani* deposited the eggs of the left ovary first, and then those of the right ovary.

As eggs are easily washed out by waves, it is very difficult to obtain them in their later stages. Even when not washed out, the

peculiar and very convenient marks of the spawn are lost after three or four days. Therefore I found it necessary to dig out eggs as soon as possible after the time of deposition and to transfer them into a large wooden box, especially made for this purpose. The box was filled with sand and was placed at the mouth of a canal. The place was happily chosen as the box was covered by water during high tide and exposed to the air during low tide, and was always exposed to the sunshine in the day-time.

In the summer of 1889 I buried eggs of different stages in the box; but in the year following I buried only two series of spawns which were deposited on the same day, and thus I could easily find out how many days old my eggs were.

Eggs one or two days old are not spherical but polyhedral by mutual pressure. At this time they are connected together by the coagulation of a fluid with which they were covered, when deposited. The average diameter of an egg is $2\frac{1}{2}$ mm. Its yolk is yellowish and glutinous; but when exposed to the air it soon loses water and changes its color to dirty green, and becomes hard, and brittle. It is covered with a thick, tough chorion which with the abundant yolk makes observations either from the surface or by section very troublesome.

Eggs were fixed by heating in water to 60°–70° C., or by plunging into hot water of the same degree. After cooling they were transferred into 70 % alcohol, in which they were left one or two days. Then in the case of eggs of early stages some of them were pierced through into the yolk with the point of a fine needle at two or three spots, care being taken not to hurt the germinal disc. These perforated eggs were left in 70 % alcohol for one or two days more, and afterwards were dehydrated in ascending grades of alcohol. The chorion is split naturally or by heating and is easily removed; but at these stages the vicarious chorion is formed. This membrane was perforated

before heating by applying the points of two fine needles from opposite points at the same time.

For the surface-view of the embryo, the ventral plate was peeled off from the underlying yolk of the preserved egg, and was stained with borax carmine, then washed in acidulated alcohol, and after dehydration and clarification was imbedded in Canada-balsam.

For the sections the eggs were stained with borax carmine or haematoxylin *in toto*. As the yolk is very abundant, the sectioning was very troublesome. In the case of the early stages in which the dorsal part consists only of the one-cell layered epiblast, I cut away this part as much as possible. By using the celloidin-paraffin method of imbedding I obtained very good sections.

I am sorry that I could not observe thoroughly the whole developmental history of the *kabutogani*, for want of sections of eggs of very early and of very late stages. My observations were made chiefly on the stages from the formation of the germinal layers to about two weeks before hatching.

External Changes.

On July 29th, 1890, I dug out two series of the spawn, which had been laid on the morning of the same day, transferred them into the box before mentioned, and examined and preserved eggs from them every day.

On August 2nd (5 days after spawning), I saw many irregular furrows on one pole of the egg (fig. 2). This was the first surface change I observed. These furrows were observed by Osborn[1] in the American *Limulus*.

1) Osborn—*Metamorphosis of Limulus polyphemus*. Johns Hopkin's Univ. Circ. vol. V. 1885.

On August 7th (10 days after spawning), I found a small round whitish disc (fig. 3). This gradually enlarged and on August 10th (13 days after spawning) it had assumed an oval shape. The longer axis of the disc corresponds to the future median line of the embryo, and the disc itself is the rudiment of the ventral plate. The disc had divided into two unequal parts by a transverse line (fig. 4). The smaller portion of the disc corresponds to the cephalic lobe and the first appendage-bearing segment. New segments are successively cut off from the anterior end of the larger, posterior portion.

On the morning of August 11th (14 days after spawning), three transverse lines and a median longitudinal line were visible (fig. 5). The median line did not extend posteriorly beyond the third transverse line. Thus at this stage the ventral plate is divided into four segments, three anterior ones of which are divided into two lateral halves by the median longitudinal line. About noon of the same day one more segment had been added (fig. 6), and the median line had been produced to the posterior end of the new segment.

On August 12th (15 days after spawning), five transverse lines were seen, and the median line was produced beyond the penult segment (fig. 7). Although the change is very gradual, yet when we compare the two ventral plates represented in fig. 5 and fig. 7, we find that the ventral plate is much larger in fig. 7. Moreover while the angle made by the lateral halves of a segment with the median line is almost a right angle in fig. 5 and in the anterior region of fig. 6, the angle has become acute in fig. 7—the acuteness increasing more and more towards the posterior end.

On August 13th (16 days after spawning), many important changes had occurred. The external ends of the segments had united with each other forming a white marginal band on each side of the

ventral plate (figs. 8, 9, *mar. bd.*). Packard[2] describes the band accurately. He says: "Around the edge (of the 'primitive disk') is a pale areola, destined to be the lower edge of the carapace; it is most distinct along the middle, merging imperceptibly into the anterior and posterior end of the disk. It is a thin ridge, due to a local heaping up of cells." Almost simultaneously with the appearance of the marginal bands, two paired longitudinal grooves are formed just internal to the band and parallel with the median line of the ventral plate. I shall call the outer of these longitudinal grooves the first, and the inner of them, the second, lateral longitudinal groove (figs. 8 & 9, *1 lat. gr.*, *2 lat. gr.*). The first appendage-bearing segment had become cut off from the cephalic lobe, *i.e.*, the first segment of the earlier stages (figs. 4 & 7) had thus been divided into the first appendage-bearing segment and the cephalic lobe. The cephalic lobe which was earlier clearly divided into two lateral halves had now begun gradually to unite (fig. 8), and in fig. 9 is seen completely united, no dark line being found in the median part of it. The sixth appendage-bearing segment had become cut off. The median line had been much produced and almost reached the posterior end of the ventral plate. The posterior part of the line is grooved.

On August 14th (17 days after spawning), the stomodaeum (*st.*) was distinctly seen in the cephalic lobe, at the anterior end of the longitudinal median line (fig. 10). It is a very shallow, roundish depression. Rudiments of the distal end of the appendages had now become distinct as round protuberances within the marginal band and were very conspicuous features of the ventral plate. In the marginal band and external to the fourth appendage, paired, round protuberances (*lat. h.*) appear. They are a little larger than the rudiments of appendages. As the function as well as homology of these peculiar protuberances

2) Packard—*The Development of Limulus polyphemus.* Mem. Bost. Soc. Nat. Hist. vol. II.

are uncertain I shall call them the *lateral humps*. The second lateral longitudinal grooves had now reached the posterior end of the fifth appendage-bearing segment. The seventh appendage-bearing segment had been newly cut off. At this time all the appendages are post-oral.

The external changes that occur before the appearance of the rudiments of all the ambulatory appendages are very hard to observe, as the ventral plate is small and pale at this time. I could not observe them in the summer of 1889, except the irregular fissures found in a very early stage.

As the result of the gradual enlarging of the ventral plate, the egg gradually flattens on the ventral side, thus producing a space filled with a clear fluid between the ventral plate and the vicarious chorion which is by this time already present. The vicarious chorion dilates greatly while the chorion outside it cannot expand equally; thus the chorion is necessarily ruptured. Two specimens of the broken chorion are represented in fig. 11. The lines of rupture are seen to go round the chorion irregularly and do not form closed circles.

On August 15th (18 days after fertilization), the eighth appendage-bearing segment had appeared. The second lateral longitudinal groove had reached the posterior end of the sixth appendage-bearing segment, beyond which the groove never elongates. The seventh appendage had appeared on this day.

On August 16th (19 days after fertilization), the ninth appendage-bearing segment had appeared (fig. 12). The eighth appendage had been produced. The median longitudinal groove, which had appeared four days before in the posterior part of the ventral plate, had become very distinct in the last undifferentiated segment. The lateral humps were not as elevated as before.

On August 17th (20 days after fertilization), the tenth appendage-

bearing segment had appeared (cf. fig. 13). The ninth appendage had been produced. The second, third, fourth, and fifth appendages had become chelate. The rudiment of the flabellum was found as a small round prominence on the outside of the sixth appendage. A similar prominence was also found in the segment of the fifth appendage. The nervous system was seen as indistinct, white, longitudinal bands near the median line. In the brain, paired invaginations were found. The marginal band had moved much farther outward, so that the outer lateral longitudinal groove had become very wide and shallow. The first appendage was found at the level of the stomodæum.

On August 18th (21 days after fertilization), mesoblastic dissepiments were found, and the homodynamous organ to the flabellum was seen in the segments of the fourth, third, and second appendages (fig. 13).

From August 19th onwards, the abdomen became gradually prominent by the development and addition of new segments. The hatched embryo has ten abdominal segments. This number corresponds to the number found in the adult animal. The sixth and the first appendages became chelate. The seventh appendage gradually degenerated from the distal end, and at last a small proximal portion only remained as the metastomum. As the ventral plate increased its surface very rapidly, the at first spherical egg became flat dorso-ventrally, and the egg assumed the trilobite-like shape (fig. 17). The lateral hump separated gradually from the marginal band and was found in the trilobite stage on the dorsal side of the embryo.

Internal Changes.

A section cut through the white disc found in the embryo (fig. 3) of August 7th is represented in fig. 21. It shows that in the disc cells

are much smaller and more crowded than in other parts of the egg. Thus the white disc is nothing more than a blastodermic thickening. This blastodermic thickening is not produced by the addition of cells from within, but by the rapid cell-division in a certain space of the surface. The cells forming other parts of the egg, both superficial and internal, are large, spherical, and all of about the same size. At this stage all the cells contain yolk granules which are smaller in the vicinity of the nucleus.

On August 8th (11 days after fertilization), the blastodermic thickening had become larger and also deeper (fig. 22), but on the next day it had increased only in the horizontal plane. At about this stage a thin transparent membrane, the vicarious chorion, is secreted from the blastodermic cells. As the blastoderm-cells become pressed together, and in consequence, polygonal grooves are formed around each cell, the vicarious chorion is tucked in to fit these grooves and presents polygonal markings with a double contour.

On August 10th (13 days after fertilization), an important change had taken place. The cells forming the blastodermic thickening had separated into two layers (fig. 24). The upper layer is composed of a layer of columnar cells and represents the epiblast, the lower layer is many cells thick and represents the mesoblast. Thus the blastodermic thickening gives rise to the epiblast and mesoblast of the ventral plate. The remaining germinal layer, the hypoblast is represented by the large yolk-cells in the interior of the egg. Outside the ventral plate, the epiblast rests directly on the hypoblast, the mesoblast being not yet found in these parts. The epiblast cells throughout are smaller than the hypoblast cells. Every cell of the egg had at this stage a distinct nucleolus. Late, on this day, the epiblast of the ventrum had become composed of cells in many irregular rows, as a consequence of rapid cell-proliferation (fig. 23).

On August 11th (14 days after fertilization, cf. fig. 5), the mesoblast layer had divided into two lateral bands (fig. 25). Since the preceding day the mesoblast had already divided into as many transverse bands as there are segments externally seen.

Late on August 12th (15 days after fertilization, cf. fig. 7), the mesoblast of the fifth appendage-bearing segment had split into two layers, somatopleur and splanchnopleur, producing a cavity—the cœlomic cavity—between them (fig. 26). As the mesoblast is divided into two lateral halves the cavity is of course paired. The fifth appendage-bearing segment was well developed, and was separated from the fourth and sixth appendage-bearing segments by deep grooves.

On August 13th (16 days after fertilization, cf. figs. 8 & 9), a short median groove had formed in the posterior part of the ventral plate. Cells underlying the groove had become loose, wandered in, and expanded into a sheet between the epiblast and the yolk-hypoblast (fig. 27). I shall call the groove the *primitive streak*. The epiblast cells of the ventral plate and most of the mesoblast cells have by this time lost their nucleolus, while the epiblast cells of the dorsum and hypoblast cells have still distinct nucleoli (fig. 41). The mesoblast of the sixth appendage-bearing segment had split into two layers, producing the cœlomic cavity.

On August 14th (17 days after fertilization, cf. fig. 10), a pair of the cœlomic cavities, common to the cephalic lobe and the first appendage-bearing segment, had appeared (figs. 29, 30), and another pair in the seventh appendage-bearing segment (fig. 31). The primitive streak had receded partly towards the posterior end of the ventral plate. The mesoblast produced from the primitive streak had separated into two lateral halves and then divided into many transverse segments. I am inclined to believe that the mesoblast belonging to the

region of the body posterior to the sixth segment (exclusive) is formed from the primitive streak. The white marginal band (figs. 8 & 9) externally observed on the preceding day was a thickening of the epiblast (*lat. bd.*) as represented in fig. 30.

The lateral hump consisted of very high columnar cells forming a little protuberance (fig. 42). The cells stain faintly. The lateral hump is a problematic organ which was formerly erroneously described by Kingsley[3] as the rudiment of the lateral eye. It was homologised to the so-called "dorsal organ" of other Arthropods by Watase.[4] Recently Patten[5] and Kingsley[6] have described it as serially homologous with the lateral eyes. I can not corroborate the last two authors, as I could not find such a peculiar organ in other segments, and because it appears at first as a *protuberance* and not as an *invagination* which it should be, if it were homologous to the eye.

The yolk granules in the cells of the ventral plate had mostly disappeared. Late on this day the nervous system had become marked off from the general epiblast by a peculiar grouping of cells (fig. 46). The arrangement of cells in the nervous system is just like that found in the retina of the compound eye for the ommatidium. Conical shaped groups of cells with spherical nuclei are surrounded by compressed and slender cells with long and deeply staining nuclei. The top of the cones is directed exteriorly. The brain and the ventral nerve-cords are formed at the same time, and are connected with each other, though their two lateral halves are formed independently (figs. 28–30).

On August 15th (18 days after fertilization), the cœlomic cavities

3) Kingsley—*Notes on the Embryology of Limulus.* Quart. Journal of Micro. Sc. 1885.

4) Watase— *On the Morphology of the Compound Eye of Arthropods.* Stud. from the Biolog. Lab. Johns Hopkin's Univ. 1890.

5) Patten—*On the Origin of Vertebrates from Arachnids.* Quart. Journ. of Micro. Sc. 1890.

6) Kingsley—*On the Phylogeny of Limulus.* Zool. Anz. 1890.

of the eighth appendage-bearing segment had appeared. Since the preceding day an incomplete septum had been produced in the first common cœlomic cavity, separating the cephalic portion from that of the first appendage-bearing segment (fig. 30).

On August 16th (19 days after fertilization), three pairs of invaginations were visible in the cephalic region. One pair was in the external part of the cephalic lobe (figs. 12, 34, 59, *ex. gr.*). I shall call it the external cephalic groove. It is the groove for the ganglion of the lateral eye. Another pair was a small roundish depression, external and posterior to the first pair (figs. 12, 35, 59, *lat. e.*). It is the invagination for the lateral eye. The third pair was also a small roundish depression in front of the cephalic lobe near the median line (figs. 12, 34, *med. e.*). It is the invagination for the median eye. The mesoblast which had been divided into lateral halves had now reunited in the cephalic region (fig. 59), and in the second (fig. 33), third, and fourth (fig. 39) appendage-bearing segments. The ninth pair of the cœlomic cavities had appeared (fig. 32).

On August 17th (20 days after fertilization), one more pair of the grooves had appeared in the internal, anterior portion of the cephalic lobe (figs. 36, 38, *int. gr.*). The new groove is long and crescent-shaped. I shall call it the internal cephalic groove. It is the groove for the brain. The tenth pair of the cœlomic cavities had appeared. The rudiment of the flabellum had appeared as a small, round protuberance formed of high, columnar cells (fig. 47). A similar, and undoubtedly homodynamous organ may be seen in the segment anterior to the segment of the flabellum, though much smaller (figs. 13 and 48).

On August 18th (21 days after fertilization), the ventral nerve-cord had divided into ganglia (fig. 13). The paired invaginations for the median eye had united (figs. 13, 36, 37). A pair of round protuberances, homodynamous with the flabellum, was found in the seg-

ments of the fourth, third, and second appendages (fig. 13). The mesoblast belonging to the fifth and sixth appendage-bearing segments had united in the median line.

Formation of the Germinal Layers.

No gastrula mouth is found in the formation of the germinal layers, but the blastodermic thickening, shown in figs. 3 and 21, similar to the primary thickening[7] of the spider's blastoderm, may be considered as a modified gastrula mouth, though in addition to the epiblast it gives rise only to the mesoblast, while the similar thickening of the spider gives rise to both the mesoblast and hypoblast besides the epiblast. Though I was unable to study the segmentation of the egg of *Limulus*, I am inclined to believe that after segmentation the egg is a solid sphere consisting of many spherical balls of similar size, each of which contains a nucleus and abundant yolk granules in it. In one spot of the egg's surface these balls are divided again and again and form the blastodermic thickening. Therefore we find many cells in the interior of the egg.

In the spider all the segmentation nuclei come to the surface of the egg, after segmentation is over, and form the one-cell layered blastoderm enclosing the yolk which is free from nuclei. At one spot of the blastoderm, cells are very rapidly multiplied and form the primary thickening. Some cells forming the lower part of the thickening wander in again into the yolk and form the hypoblast.

These two types in the formation of the germinal layers, exemplified in *Limulus* and in the spider, are often found in closely related groups of Arthropods, and neither of them is of rare occurrence. I think that the type of *Limulus* is an abbreviation of that of the spider. In the former the hypoblast cells, instead of coming out of the

7) Kishinouye—*On the Development of Araneina.* This Journal, vol. IV.

yolk and afterwards returning to it as in the spider, remain in it from the time of their formation.

The epiblast in *Limulus* is derived in two different ways. The epiblast of the ventrum arises from the superficial layer of cells of the blastodermic thickening, separating from the lower cells, while the epiblast of the dorsum is differentiated from the immediately underlying hypoblast cells by rapid multiplication, thus forming a single layer of columnar cells (fig. 41).

The mesoblast of *Limulus* has three sources. One portion arises from the cells forming the lower part of the blastoderm thickening. This portion forms the mesoblast of the cephalothorax. The second portion arises from the primitive streak. After the separation and differentiation of the cells of the blastodermic thickening into the epiblast and mesoblast, and after the metamerism of the ventral plate has already begun, a median longitudinal groove, the primitive streak, is found near the posterior end of the ventral plate. From the bottom of the groove many cells become loose and proliferate vigorously between the epiblast and hypoblast. These cells form the mesoblast of the abdomen (probably the mesoblast of the last thoracic segment also). The primitive streak is found even in an embryo about three weeks old (fig. 32). It recedes gradually posteriorly giving rise to paired sheets of the mesoblast. It may be compared to the secondary thickening, the caudal thickening, of the spider's blastoderm, though the latter is produced before the differentiation of the germinal layers, thus of course before the appearance of metamerism. The primitive streak of *Limulus* is probably homologous with the structure of the same name in the *Chordata*. The section shown in fig. 27 has a striking resemblance to a section across the primitive streak of a chick. The third portion of the mesoblast arises from some yolk cells. In later stages some yolk-cells losing the yolk granules come out of the

yolk and mix themselves with the mesoblast cells (figs. 40, 41, *mes'*). This takes place chiefly in the dorsum. These secondary mesoblast cells may be compared to the fat cells of the spider. I was unable to trace the fate of these cells, but think that some of them probably become blood corpuscles.

In early stages, just after the separation of the epiblast and mesoblast in the blastoderm thickening, we find often some large cells in the deep part of the mesoblast (fig. 24), and these gigantic cells seem to play an active part in the multiplication of the mesoblast cells.

Mesoblast and Segments.

The mesoblast after its formation extends very rapidly, chiefly by division, which takes place mostly near the ventral median line. The dorsal (distal) end of the mesoblastic somites is gradually pushed towards the dorsal surface. In these parts the karyokinetic figures are rarely found, the cell multiplication taking place, as just stated, chiefly by the division of cells in the ventral plate. The mesoblast cells in the dorsal part of the second, third, and fourth appendage-bearing segments become loose and spherical (fig. 39, 40).

I can not say whether the metamerism arises from the change in the epiblast or from that in the mesoblast. When the metameric division takes place, the mesoblast of the ventral plate is divided into transverse segments between which the epiblast is grooved.

The order of the separation of the segments is as follows ;—First a common segment for the cephalic lobe and the first appendage-bearing segment is cut off as the smaller anterior part of the ventral plate (fig. 4). Then from the larger posterior portion the second, third, fourth, fifth, &c. appendage-bearing segments are successively cut off. When the sixth appendage-bearing segment is formed, the first

appendage-bearing segment is separated from the cephalic lobe. After two or three segments are cut off, the mesoblast of the ventral plate is divided in the median line into two lateral halves, beginning from the anterior end. In early stages the dark lines in the ventral plate, where few or no mesoblast cells are found, show from the exterior the division of the mesoblast into transverse segments as well as into two lateral halves (figs. 4–7).

The mesoblast which was separated into lateral moieties unites again from the anterior end of the ventral plate. Afterwards there is found a special compact accumulation of mesoblast cells in the median line of the cephalothorax above the nervous system (figs. 51, 52, 56, 68, *entost.*). This accumulation is laterally very thick. It is the rudiment of the entosternite.

About three weeks after fertilization, the mesoblastic dissepiments are formed in the cephalothorax by the sinking in of mesoblast cells into the yolk (figs. 52, 57). They are intersomitic, dividing the yolk into as many compartments as there are segments. But there is no dissepiments between the cephalic lobe and the first appendage-bearing segment, and the dissepiment between the second and third appendage-bearing segments and that between the sixth and seventh appendage-bearing segments are short. In the abdomen the dissepiments are not well developed.

Cephalothorax and Abdomen.

The cephalothorax consists of the cephalic lobe and the succeeding seven segments. It forms the greater part of the egg, and becomes gradually flat by the horizontal increase of the ventral plate.

The development of the abdomen takes place very late. At about the time when the two mesoblastic plates of the seventh appendage-

bearing segment unite in the dorsal median line, the abdominal part becomes prominent, as the yolk is then forced into it and as the epiblast and mesoblast increasing by rapid cell-division produce a projection (figs. 15. 16). Thus the abdomen comes to be distinguished from the cephalothorax. The yolk always plays a passive part.

The peculiarity of the abdomen is that the yolk is found in the later stages in the middle portion (rachis) only (figs. 54, 55), while the cephalothorax is entirely filled up with the yolk. In the abdomen the epiblast with the enclosed mesoblast extends as two large wings *(pl.)* on either side. In these wings there is no yolk. The coelom is also not found in these wings.

The appendages borne on the abdomen differ greatly from those on the cephalothorax, remaining to the last as flat, band-like prominences, compressed antero-posteriorly, and the two lateral members afterwards uniting more or less at the ventral median line (fig. 55).

A little before hatching the abdomen consists of ten segments, (the number equal to that found in the adult animal) the four anterior ones of which bear the appendages (fig. 56).

Appendages.

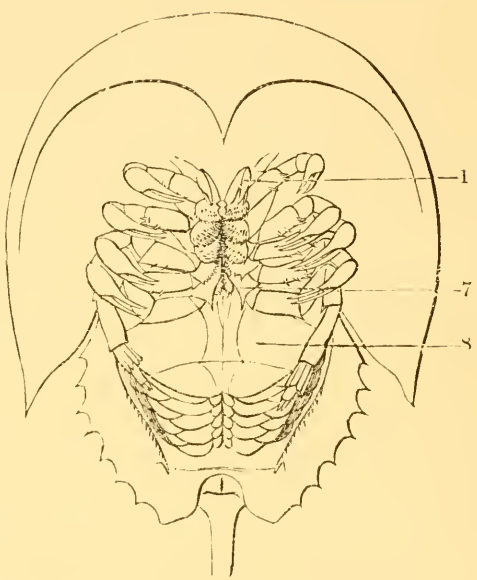
The first rudiments of the appendages appear in the stage of fig. 7. It is not right to consider the round protuberances found in figs. 8, 9, 10, as the first rudiments of appendages, and the bases of the protuberances as the external extremities of the segments. A groove is produced between every two segments. It is deeper towards the lateral ends. Thus a pair of band-like prominences may be found in every segment. Such a prominence is the rudiment of an appendage. When the appendage is thus far formed, a groove, the first lateral groove, appears at the lateral edge of the segment on each side (figs. 8, 9, 10.

1 lat. gr.). Shortly after this, a second lateral groove is formed, parallel and internal to the first lateral groove (figs. 8, 9, *2 lat. gr.*). Thus in some segments arise round protuberances bounded by the lateral grooves and transverse grooves. These protuberances are the rudiments of the *distal* portion of the appendages. The epiblast is now tucked in from the external side of the protuberances, thus separating the band-like portion internal to the protuberances from the general surface of the subjacent body (fig. 33). The band-like portions thus cut off are the rudiments of the *proximal* portions of the appendages. Three distal joints (four in the last ambulatory leg) are developed from the protuberances, and three proximal joints from the flat band-like portions.

Though the appendages (especially the anterior six pairs) appear almost simultaneously, yet by a close examination I found that the fifth appendage appears first, and gradually forwards the fourth, third, second, and first appendages are formed; then gradually backwards the sixth, seventh, eighth, &c. appendages. The rudiments of all the appendages are almost alike. The order of the differentiation of the distal portion (round protuberances) of the appendages does not coincide with the order of the appearance of the appendages themselves. The differentiation begins at first in the fourth appendage, and proceeds in others successively to the first appendage, then gradually in the opposite direction in the fifth and sixth appendages. From the seventh appendage (inclusive) posteriorly, the second lateral groove is not formed. Thus all the abdominal appendages develop from the band-like prominences and finally assume a leaf-like form.

The six anterior appendages become afterwards chelate. The first appendage does not develop as vigorously as the others. It remains small and slender and is afterwards placed before the mouth and becomes the chilaria or antenna. The following five appendages become

the ambulatory legs, the four anterior ones of which are later six jointed, while the last one is seven jointed. The last ambulatory leg differs from the other ambulatory legs also by having four rod-like appendices at the base of the sixth joint. The presence of these appendices enables the last ambulatory leg to serve for digging. The seventh appendage gradually degenerates from the external side (fig. 14), leaving a small proximal portion only, which becomes the metastomum of the adult.



Limulus longispina. 1/5.
(Ventral side).

1, Chilaria; 7, Metastoma;
8, Operculum.

The appendages from the eighth backwards belong to the abdomen. The eighth pair of appendages becomes the operculum (figs, 10, 12–14, 53–57, *op.*). The right and left members of it unite secondarily with each other to a great extent and form a single plate (figs. 54, 55). The proximal portion of the operculum contains the mesoblast cells, but the distal portion does not. Hence the proximal portion is very much thicker than the distal portion (figs. 53, 54). The mesoblast is differentiated into muscles. The 9th–13th appendages bear the gill-lamellae. Among them the ninth pair is the earliest developed. In embryonic stages, the two lateral members of the pair are united at the median line only for a slight length (figs. 54, 55). Like the operculum the appendage is thick at the proximal portion (figs. 49, 53, 57). The epiblast of the posterior side of the thick portion is invaginated by many transverse furrows. The least

number of the furrows which I observed was three. The number increased to five, then six (in the stage of figs. 17, 54, 57), new furrows being added posterior to the older ones. The embryo, soon after hatching, has only four pairs of the abdominal appendages, and the second pair alone bears the gill lamellae.

The peculiar appendix, the flabellum, at the exterior base of the sixth appendage develops from a small round protuberance (fig. 13). The homodynamous protuberances are also found in the segments of the 2nd–5th appendages; but they do not develop any further and disappear.

Nervous System.

The lateral halves of the nervous system develop independently of each other. Each half of the brain with its corresponding ventral nerve-cord is produced as a continuous long cord of epiblastic thickening, just inside the base of the appendages (figs. 12–14). It is easy, however, to distinguish the brain from the ventral nerve-cord. When they are first formed, the former is very much broader than the latter, occupying almost the whole of the segment of the cephalic lobe, while the ventral nerve-cord occupies only about one third of the breadth of each appendage-bearing segment (fig. 12).

In the stage of fig. 12 we see most distinctly that the nervous system consists of peculiar cell-groups like the ommatidia of the eye (figs. 34, 36, 38, 46). These peculiar cell-groups of the nervous system were first noticed by Patten. They disappear when the ventral nerve-cord is divided into ganglia and begins to be separated from the epiblast.

A paired small invagination appears in the lateral part of the

brain (fig. 34 *ex. gr.*). The invagination is in the margin of the brain where none of the peculiar cell-groups above referred to is found. After the appearance of this invagination there is found another paired epiblastic invagination, along the anterior internal corner of the brain (figs. 13, 36, 38. *int. gr.*). This new invagination is also on the margin of the brain, where the peculiar cell-groups are not found. I believe that the external invagination is homologous with the invagination of the lateral vesicle of the spider and the internal one to the semicircular groove. These cephalic invaginations of Limulus, however, are very shallow and disappear before the separation of the nervous system from the epiblast takes place. They are already not found in the embryo in the stage of fig. 14. But the two cell-masses which were thus invaginated are found separate in the deep part (figs. 37, 51). The part of the brain formed by the external groove becomes the optic ganglion of the lateral eyes as in the case of the spider. The optic ganglion of the median eyes is produced from the epiblastic thickening forming the united mouth of the invagination for the median eyes (fig. 69, *g. med. e.* see infra). The thickening is always between, and touches on each side, the two cephalic ganglia (figs. 14, 37, 69).

At first the anterior and lateral borders of the brain were directly on the anterior and lateral borders of the ventral plate; but as the growth of the brain lags behind that of the ventral plate, it becomes gradually separated from the margin of the ventral plate.

The brain which was almost circular in its outline, as its height was almost equal to its breadth (figs. 12, 34), becomes afterwards semicircular (fig. 13), later still, sickle-shaped (fig. 14), and shortly before hatching almost straight (fig. 69). This is caused probably by the peculiar development of segments. All the segments seem to develop most vigorously at the line midway between the ventral and

dorsal median lines, *i.e.*, all the segments have their greatest antero-posterior extension on this line, and become shorter and converge, like the frame-pieces of a folding fan, towards both the ventral and dorsal median lines. Therefore the external ends of the brain are pushed anteriorly by the growth of the succeeding segments. About two weeks before the hatching of the embryo the brain proper becomes divided into two transverse portions by a constriction (fig. 69). Thus the brain of *Limulus* may be divided into four parts—the ganglion of the median eyes, the ganglion of the lateral eyes, and the anterior and posterior portions of the brain proper. These four parts are arranged in three transverse rows. The anterior row is occupied by the two pairs of the optic ganglia, the middle row by the anterior portion of the brain proper, and the posterior row by the posterior portion of the brain proper (fig. 69).

Though the posterior portion of the brain proper is very early (earlier than any other part of the nervous system) cut off from the epiblast, and the fibrous commissure is developed between the right and left sides (figs. 45, 51, 69), its anterior portion as well as the two pairs of the optic ganglia are for a long time not separated from the epiblast (fig. 56).

The ventral nerve-cord consists at first of one continuous longitudinal thickening of the epiblast (figs. 12, 30, 33). The thickening is at this time distinguished by the peculiar cell-groups already mentioned. At about the stage of fig. 13, the thickening is divided into ganglia, as the cells composing it accumulate into a mass in every segment. A pair of such ganglia may be found in each of the segments of the first and seventh appendages as in the other segments. The ganglia of the first and the second appendage-bearing segments form the circumœsophageal ring (figs. 51 and 69).

Lying between the two lateral members of the ganglia there are

found some epiblast cells (fig. 68, *m.c.*). These epiblast cells seem to take no part in the formation of the lateral commissure. They form probably the membrane covering the nervous system.

Cells of the nervous system, facing the centre of the egg and lying near the median line of each nervous thickening, become changed into fibres. The fibres of the ganglia as well as those of the brain and of the optic ganglia of the lateral eyes communicate with one another and form the longitudinal commissure (fig. 51). The fibres develop internally and form the lateral commissures (figs. 14, 45, 52). There is only one lateral commissure in the brain :—at the posterior portion of the brain proper (fig. 69). The lateral commissure does not develop in the segments of the first and second appendages (fig. 51). The fibrous portion of the ventral cord develops externally and innervates the appendages (figs. 14, 52, 69).

Eyes.

The lateral eyes make their appearance as small epiblastic thickenings with shallow invaginations, just at the margin of the ventral plate, and at about the level of the posterior end of the external cephalic groove (figs. 12, 35, 59, 60). At this stage they are not distinctly seen in the preserved eggs nor in the surface-view preparations. They are distinctly seen in sections only. This is due to their very small size and also to their being placed near the cephalic thickening of the nervous system and near the anterior end of the thick marginal band. But in one or two days after their formation when they are a little removed exteriorly and posteriorly from the cephalic thickening (fig. 13), and then from the marginal band (fig. 14), they become easily recognisable in the surface-view preparations. As they are thus removed, the opening of their invaginations is directed posteriorly and dorsally. The thickening is more than one-cell thick.

It is interesting that the lateral compound eye of Limulus is at first an epiblastic thickening with an invagination like a simple eye, and not a group of thickenings or invaginations, and that it appears at the outer margin of the brain, as in the case of other Arthropods. The lateral eyes of Limulus are not thoracic eyes, but cephalic eyes. After their formation they shift their position gradually dorsally and posteriorly and at last they are behind the lateral hump, at the level of the fourth appendage (fig. 17).

Cells forming the bottom of the invagination of the lateral eye become large and are faintly stained by a colouring solution (fig. 62). The invagination is faintly divided towards the posterior end into two branches or depressions, ventral and dorsal. The large faintly stained cells are found in the ventral branch only. The dorsal branch is very short and is soon aborted. The invagination of the lateral eye is not deep, and its bottom prolonged anteriorly as a short solid tube (fig. 63).

After the disappearance of the dorsal branch of the invagination, cells forming the thickening, dorsal to the invagination, are pigmented and grouped into rudimentary ommatidia (figs. 64–66), smaller and more pigmented cells surrounding larger and less pigmented cells. Each of these groups of larger cells is spindle-shaped. Thus at this time there is not to be found a separate invagination for each ommatidium. The first differentiation in the lateral eyes is the grouping of their constituent cells into rudimentary ommatidia. I do not consider the invagination for an ommatidium as of much value, as it seems to me to be produced secondarily by the thickening of the cuticula into the lens. The changes which take place in the lateral eyes after the formation of the rudimentary ommatidia are not minutely known to me.

The optic nerve of the lateral eyes is formed from the lengthening of cells forming the solid prolongation of the invagination (fig. 66),

and in the embryonic stages does not communicate with the brain. From the adult anatomy and from the analogy of the spider, I consider the portion of the brain formed by the external groove as the optic ganglion of the lateral eyes.

The lateral compound eye of *Limulus* is homologous with the group of the lateral simple eyes of the Arachnida. For the lateral simple eyes of the Arachnida arise as a group from a common epiblastic thickening—as I have recently shown in the Dōbutsugaku Zasshi (the Zoological Magazine, Japanese) and as is set forth in the article immediately following in this Journal. The lateral eyes of the scorpion are most nearly related to the lateral compound eye of *Limulus*, as they are monostichous and are placed close to one another.

The median eyes appear as paired invaginations in paired epiblastic thickenings near the median line and in front of the cephalic thickening (fig. 12). They are formed just outside the brain (figs. 34, 38), so that they are not neural in origin. The paired invaginations afterwards approach each other (fig. 13), and finally form a median unpaired invagination (figs. 14, 36, 37). This unpaired invagination becomes deep and slender and develops anteriorly and dorsally, its blind end touching the epiblast (figs. 50, 56). The lumen of the invagination is lost as it becomes exceedingly slender, and at this stage the median eyes are represented by a slender solid rod (fig. 51). Later the extremity of the rod becomes enlarged and at the same time epiblastic cells lying on it becomes columnar (figs. 56, 67). The enlarged extremity becomes the retina and the columnar epithelium forms the vitreous body.

The mouth of the invagination is closed, when the tube of the invagination becomes solid. The epiblast where there was originally the mouth of the invagination is thick and slightly depressed (figs. 68, 69). This thickened area of the epiblast probably gives rise

to the ganglia of the median eyes, and the slender stalk which connects this area with the retinal portion to the optic nerve.

I was unable to study the later changes of the median eyes. Their development greatly lags behind that of the lateral eyes. I do not know whether the anterior end of the retinal cells is morphologically the anterior end or not. The unpaired retinal portion is afterwards divided into two and gives rise to two median eyes in the adult. That the median eyes of *Limulus* are homologous with those of the *Arachnida* is most probable; but it is a little doubtful whether they are exactly homologous in every respect. Thus the median eye of *Limulus* appears as a thickening anterior to the brain and outside the semi-circular cephalic groove, while that of the Arachnida appears as a thickening at the posterior end of the semi-circular cephalic groove.

I find no more eyes than the two pairs mentioned above, nor any other structure which I can consider as homologous with them.

Alimentary Canal.

The stomodaeum is first of all produced as a shallow round invagination in the cephalic lobe (figs. 10, 29, *stom.*). The invagination becomes gradually deep and takes an anterior and upward course (figs. 50, 68). When it almost reaches the dorsum it bends a little backwards. At first it develops with the surrounding mesoblast between the epiblast and the yolk-hypoblast (fig. 50); but later, the yolk finds its way into the region in front of the stomodaeum, so that in sections, we find masses of yolk before the stomodaeum (fig. 52, C+I; and fig. 56). The stomodaeal wall consists of high columnar cells (figs. 45, 68). The stomodaeum gives rise to the œsophagus and proventriculus. As the upper lip grows posteriorly, the mouth-

opening which was at first pre-appendicular gradually shifts its position backward and becomes surrounded by the cephalothoracic appendages.

The proctodaeum is not well marked out. In the sagittal section represented in fig. 50, we see an invagination at the posterior end of the body. The invagination is crescent-shaped, as represented by the horizontal section, fig. 53, and is continued to the grooves produced by the ventral reflexion of the pleurae *(pl.)*. Therefore the invagination can not be considered as the proctodaeum.

I could not find any trace of the mesenteron at all, even in the embryo of the trilobite stage (fig. 17). According to Brooks and Bruce, the proctodaeum and the mesenteron do not appear in the embryonic stages.

Cœlom.

The early development of the cœlom may easily be understood by examining figs. 12–17. The cœlomic cavity is produced by the splitting up of the mesoblast into the somatopleur and the splanchnopleur. The somatopleur is thicker than the splanchnopleur, the former being many cells thick, while the latter consists of a single layer of cells (figs. 29–32). When the cœlomic cavity is produced, the mesoblast is already divided into many transverse segments, in every one of which the mesoblast is separated into lateral halves, so that the cœlomic cavities are always paired in a segment. Though the lateral halves of the mesoblast afterwards fuse together secondarily at the ventral median line, the cœlomic cavities of both sides remain always separate. The walls of the first cœlomic cavity fuse together along the whole line in which the two lateral members meet—from the ventrum up to the dorsum. From

the second cœlomic cavity backwards the walls of the two lateral members do not fuse together at the dorsal, though they do at the ventral median line.

A pair of cœlomic cavities appear in every segment, except the segments of the second, third, and fourth appendages, in which the cœlomic cavity does not appear at all. At least eleven pairs of these cavities are produced (fig. 53). The eleventh pair belongs to the seventh abdominal segment.

All the cœlomic cavities develop towards the dorsum between the epiblast and the hypoblast, and meet with one another at the dorsal median line (figs. 17, 43, 44). They develop just above the hypoblast and do not enter nor give branches into the epiblastic outgrowths, such as the appendages and the abdominal pleurae (figs. 53–55).

The first pair of cœlomic cavities is common to the cephalic lobe and the segment of the first appendage (fig. 12). A little later this common cœlomic cavity is partially divided into two by an incomplete septum between the cephalic lobe and the segment of the first appendage (figs. 12, 30); but as the cœlomic cavity gradually degenerates from the posterior end, the smaller portion belonging to the segment of the first appendage disappears soon after its formation (fig. 13). The first cœlomic cavity always accompanies the stomodæal invagination (figs. 45, 50, 52). As the stomodaeum does not develop always along the external epiblast and as its distal end takes gradually an upward and then backward direction, and grows into the yolk mass, the first cœlomic cavity is necessarily embedded among the yolk (fig. 52). Taking the upward and then the backward direction the first cœlomic cavity reaches at last the dorsum and there meets with the wall of the second cœlomic cavity, which has grown forward to this point (fig. 17).

The second cœlomic cavity belongs to the segment of the fifth

appendage. It is well developed. From the segment of the fifth appendage backwards, a pair of cœlomic cavities develop in every segment. These cœlomic cavities develop at first in a dorsal and posterior direction. The second and third cœlomic cavities are divided into two portions each—ventral and dorsal—as the cells forming the middle part of their wall become loose and fill up the cavity (figs. 14, 58). The ventral portion of the second cœlomic cavity remains as the coxal gland, while that of the third cœlomic cavity disappears soon after its separation (fig. 14). From the fourth backwards cœlomic cavities gradually disappear from the ventral median portion (fig. 55). The dorsal portion of the cœlomic cavity remains long at the sides of the circulatory system (figs. 54–56); but it disappears before the embryo hatches. The dorsal portion of the second cœlomic cavity elongates anteriorly and meets with the posterior end of the first cœlomic cavity (fig. 17).

Coxal Gland.

The brick-red gland of Packard is mesoblastic in origin, and the lumen of the gland is the remnant of a portion of the second cœlomic cavity. The gland develops from the ventral portion of the second cœlomic cavity, which belongs to the segment of the fifth appendage. Almost simultaneously with the separation of the cœlomic cavity into the dorsal and ventral portions, one layer of cells enclosing the ventral portion is separated from the other mesoblastic cells, (which are used to form connective tissue, muscles, entosternite, &c.,) and causes that portion to have the shape of a sac or tube. The sac is the rudiment of the coxal gland. The cells forming the wall of the gland are

pressed close together. They have a high columnar shape near the ventral median line; but as we recede from that line they become almost suddenly low, flat, and loose, and are lost in loose, scattered, connective tissue cells (figs. 52, 58). This thin walled portion becomes the funnel of the gland.

The coxal gland is at first straight and obliquely directed; but soon afterwards a small axial portion of it near the median ventral line is bent backwards parallel to the median line making almost a right angle with the rest of the gland (fig. 14). The apex of the angle is now gradually shifted forwards; the result being that the angle becomes more and more acute, as the limbs of the angle increase in length, while the distance between their bases remains almost constant. The posterior end of the internal limb of the gland develops a little downwards and then backwards till it touches the posterior surface of the coxal joint of the fifth appendage, where it is connected with the epiblast and makes the lumen of the gland communicate freely with the exterior. The coxal gland at this stage is represented in fig. 19. Its anterior apex reaches the mesoblastic dissepiment between the third and fourth appendage-bearing segments. Its external limb is arched externally, the key-stone of the arch being at the mesoblastic dissepiments between the fourth and fifth appendage-bearing segments. The funnel is directed outwardly and posteriorly and is in the mesoblastic dissepiment between the fifth and sixth appendage-bearing segments.

In the next stage (fig. 20) the anterior apex of the gland has reached in its growth the mesoblastic dissepiments between the second and third appendage-bearing segments, and another curvature—this time towards the mesoblastic dissepiment between the third and fourth appendage-bearing segments—has been added to the external limb. When the gland of this stage is seen from one side, its external

limb presents many wave-like curves. The number of these curves corresponds with that of the metameres in which the gland extends. The limb presents a dorsally directed curvature at each mesoblastic dissepiment. There is thus a dorsal as well as outward curvature over each of these dissepiments. The coxal gland in such a stage of development is found in an embryo of about the stage of fig. 17. The further development of the gland I did not follow.

The coxal gland is probably a degenerated excretory organ, as in development, position, and structure it is similar to the excretory organs of other animals. It is on both sides of the entosternite (fig. 52).

The coxal gland of *Limulus* is not exactly homologous with that of the spider. In the latter, the gland opens at the base of the third appendage and reaches about to the base of the sixth appendage, while in *Limulus* the gland opens at the base of the fifth appendage and develops forwards to the base of the third appendage.

Vascular System.

The chief dorsal circulatory vessel is formed from the mesoblastic wall of the cœlomic cavity. As the walls of the lateral halves of the succeeding cœlomic cavities unite gradually, beginning with the posterior segments (figs. 15, 16), the dorsal circulatory vessel is formed, *pari passu*, from the posterior end of the body. Though the walls of the cœlomic cavities on both sides meet in the dorsal median line, they do not fuse together (figs. 17, 43, 44). A longitudinal and many transverse slits separate every cœlomic cavity from its fellow on the opposite side of the same segment, and from the preceding and succeeding cœlomic cavities of the same side (figs. 15–17). The

lateral halves of the first cœlomic cavity only are fused together and not separated by a longitudinal slit (figs. 16, 52). In later stages, however, the walls of all the cœlomic cavities fuse together at two lines, dorsal and ventral. Thus a tube is formed (figs. 54–56). The tube, as in the case of spiders, has many lateral slits (ostia), as the wall does not fuse together at the intersomitic lateral places. In the tube some wandering mesoblast cells are enclosed. They are destined to become blood corpuscles. Probably all the blood corpuscles are formed from these cells.

As no cœlomic cavity is developed in the segments of the second, third, and fourth appendages, the mesoblast of these segments plays no part in the formation of the wall of the dorsal circulatory vessel. The first cœlomic cavity, which belongs both to the cephalic segment and to the segment of the first appendage, also does not take part in the formation of the dorsal circulatory vessel, because the walls of its two halves are fused together as stated above (fig. 17).

When the dorsal vessel is not yet completely formed, the aortic arches (*ao. a.*) are produced at the sides of the œsophagus (figs. 17, 45). A tubular lumen appears in the mesoblastic wall of the first cœlomic cavity, where the somatopleur and splanchnopleur unite, between the cœlomic cavity and the œsophagus. The lumen is paired. The lumina of the two sides unite into one and communicate with the lumen of the dorsal circulatory vessel, at the posterior end of the blind stomodæum (fig. 17).

While the aortic arch is thus developing, a large unpaired blood space (*st. a.*) appears below the entosternite (*entost.*) and around the nerve cords on the ventral median line (figs. 50–52, 56, 58, 68). This is the sternal artery, which communicates anteriorly with the aortic arches in later stages.

I can not but think that Kingsley is mistaken in regard to the

vascular system of the American *Limulus*, and that it will be found to be formed in the same way as the Japanese species. The number and position of the ostia of the American *Limulus* (fig. 18) agree exactly with those of the embryo of the *kabutogani* (fig. 17).

Dorsum and Ventrum.

The compound eyes of the adult *Limulus* are very peculiar in this that they lie in the thoracic region and on the dorsal surface of the cephalothorax. Previous writers differ in their opinions, as to what thoracic segment the lateral eyes belong to, though all of them allow that the lateral eyes are thoracic. If now the lateral eyes really belong to a thoracic segment, it is an exceedingly interesting fact, for there is no parallel in other animals.

When we look into the matter more carefully, we are struck, first of all, with the fact that the lateral eyes are innervated from the brain —a fact well known for a very long time. Now if they really belong to a thoracic segment, they ought to receive their nerves from the ganglia of that segment, and it is, to say the least, very peculiar that they should be connected with the brain and not with the ganglia of a thoracic segment.

Examining the adult animal (fig. II) we find that the dorsal surface of the cephalothoracic shield is divided into five, while that of the abdominal shield is divided into three longitudinal lobes, as in the Trilobites (fig. V). These lobes I name after the corresponding lobes of the Trilobites—the median unpaired lobe as the *glabella* in the cephalothorax, and as the *rachis* in the abdomen, the first (internal) paired lateral lobes as the *fixed cheeks* in the cephalothorax, and as the

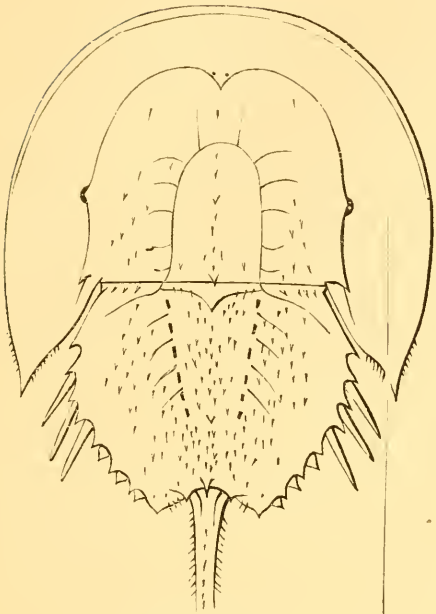


Fig. II.

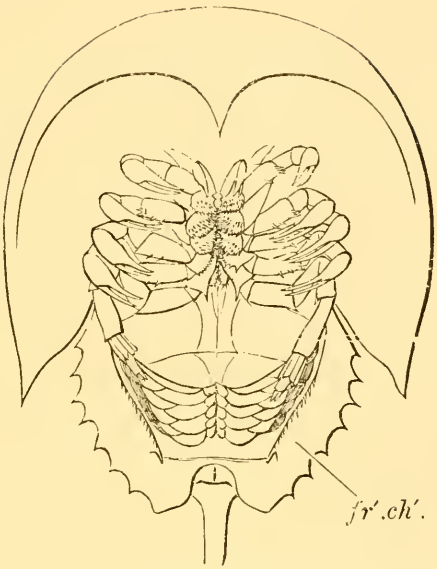


Fig. III.

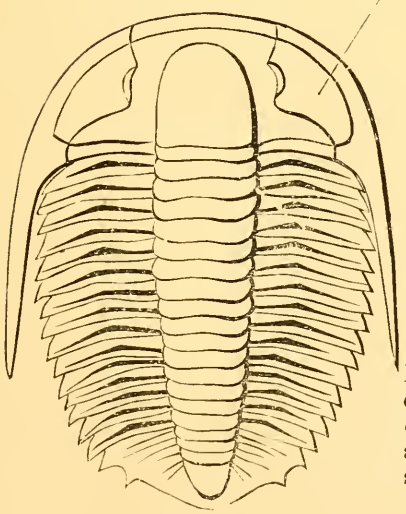


Fig. V.

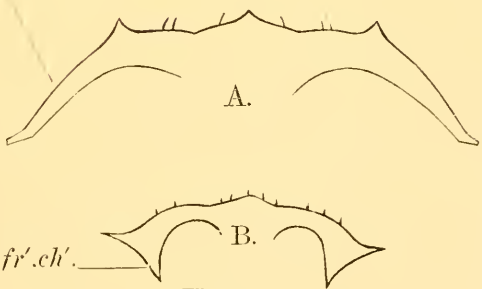


Fig. IV.

Fig. II.—IV. Limulus longispina 1/5. Fig. IV. A. Transverse section through the cephalothorax at the level of the lateral eyes. B. Transverse section through the abdomen at the level of the second lateral spine.

Fig. V. A Trilobite (Angelina Sedgwickii). *After Nicholson.*

pleurae in the abdomen, and the second (external) paired lateral lobes, which appear only in the cephalothorax, as the *free cheeks (br. ch.)*.

Also after the corresponding structure of the Trilobites, I name the furrow which separates the median lobe from the first lateral lobe as the *axial furrow*, and the suture between the first and the second lateral lobes as the *facial suture*.

It is remarkable that in *Limulus* the spines, movable and immovable, are found on the facial suture of the cephalothorax and the margin of the abdomen, and within these boundary lines only (figs. II–IV).

It is also very remarkable that the eyes are found below the facial suture only. The Trilobites, in which the facial sutures of both sides generally do not meet in the dorsal median line, have no median eyes (fig. V). *Harpes* among the Trilobites, and *Limulus* in which the facial sutures of both sides meet in the dorsal median line, have the median eyes.

In some Trilobites such as *Æglina*, the free cheeks are not well developed ; they are not seen from above, hence the lateral eyes are at the lateral margin of the cephalothorax. In these forms the fixed cheeks are also very feebly developed. I regard this type, which is found in most Arthropods as the prototype of the cephalothorax. In *Phacops* etc., the free cheeks are a little seen from the dorsal side. In the majority of the Trilobites the free cheeks are well developed at the lateral sides of the fixed cheeks ; and in *Harpes* and *Limulus* they are enormously developed, at the lateral sides as well as in front of the fixed cheeks. In these animals the cephalothorax is much broader than the abdomen.

In the ventral surface of the abdominal shield of *Limulus* we find a region (figs. III, IV, *fr.' ch.'*) corresponding to the free cheek of the cephalothorax. It is an elevated portion of the lateral edge.

The development of the eyes, which I have described above, shows that they (both lateral and median eyes) arise from paired epiblastic thickenings, just at the margin of the epiblast of the ventral

plate. The lateral eyes, however, gradually travel from the thickened margin of the ventral plate exteriorly and posteriorly, until they are found in the dorsal surface of the embryo, behind the lateral hump in the level of the fourth thoracic appendage. The invagination of the median eyes becomes gradually deep, and while the mouth of the invagination does not shift its place, with respect to the brain, the invaginated tube grows anteriorly and dorsally, keeping its blind end always in contact with the epiblast. Its development soon surpasses that of the thickened margin of the ventral plate, and at last its tip is found at the dorsal surface of the embryo. In the trilobite-stage (fig. 17) the epiblast is thickened in a line above the eyes (fig. 64).

I propose to interpret the above stated facts as follows: The epiblast, covering the body of *Limulus* may be distinguished into the dorsum and ventrum, and the line in which they meet is clearly marked out as the external margin of the pleurae in the abdomen, and as the facial suture (the outer margin of the fixed cheeks) in the cephalothorax. The ventrum is the epiblast which develops from the upper layer of cells of the blastodermic thickening, and the dorsum is the descendant of the epiblastic cells covering all the surface of the egg except the blastodermic thickening. Thus the free-cheeks which are usually looked on as a part of the dorsum are in my opinion, a part of the ventrum. If we accept the view that the original blastopore is in the ventral median line of the Arthropoda and the stomodæum and the proctodæum are its two ends, and that the segments of the Arthropoda are homologous with the compartments of the Coelenterata, then the ventrum as defined above, corresponds to the subumbrella of the medusae, all the important organs being produced from it and the dorsum to the exumbrella. The margin of the umbrella, *i.e.*, the boundary line between the two, has all the sense-organs on it.

At the time when the eyes are first formed, the ventrum and the

ventral plate are one and the same; but later the ventral plate does not keep pace in its growth with the ventrum. The ventrum extends very quickly, as is known from many karyokinetic figures in it, while the dorsum seems to increase very little after its formation (after the differentiation from the underlying hypoblast), if it increases at all. As the result of this increase of the ventrum, the egg is flattened dorso-ventrally, and the ventrum is in the cephalothorax reflexed upwards and forms apparently a part of the dorsum, and in the abdomen is elevated as in fig. IV. The retinal portion of the eye is always at the margin of the ventrum, just as the eyes of the medusae are always on the umbrellar margin, between the exumbrella and the subumbrella.

The margin of the ventrum of the cephalic lobe develops not only dorsally but also posteriorly. Thus, though the lateral eyes are found at the level of a thoracic appendage in later stages, they are not produced there, but are formed in the cephalic lobe like the eyes of other bilateral animals.

Table showing the chief early changes of the Kabutogani's eggs, which were fertilized on July 29, 1890.

	SEGMENT.										CŒLOM.										APPENDAGE.								
	br.	1	2	3	4	5	6	7	8	9	10	br.	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9
Aug. 10																															
11																															
12																															
13																															
14																															
15																															
16																															
17																															

Relation of Limulus with Other Arthropods, with Some Remarks on the Arthropod Ancestry of the Chordata.

The closest relative of *Limulus* among the Arthropoda is undoubtedly the Trilobites. The relations between them have already been given in the previous section. Though the appendages and the internal structure of the Trilobites are but little known, their external features match those of no other animal so well as those of *Limulus*. The five-lobed cephalothorax, the three-lobed abdomen, and the eyes under the facial suture, are the characteristic features of both *Limulus* and the Trilobites. These characteristics are not distinctly found in other animals, even if not entirely wanting. Moreover, *Limulus* and the Trilobites resemble each other in their habitat—swarming in the muddy bottom of a shallow sea.

The chief differences between *Limulus* and the Trilobites are as follows:— In the Trilobites, some anterior abdominal segments are separate, while in *Limulus* all the abdominal segments except the last one are united into a single shield. In the Trilobites some posterior abdominal segments are united and form the pygidium, while in *Limulus* the last segment is separate from all the other abdominal segments and forms the sword-like telson. In the Trilobites the two lateral lobes of the free cheeks are generally not united in the dorsal median line, and the median eyes are generally absent*, while in *Limulus* the two lateral lobes of the free cheeks are united in front and a pair of the median eyes is present.

Those differences are not of much importance and do not speak against a close relationship existing between the Trilobites and *Limulus*.

The next near allies of *Limulus* are the Merostomata (*Eury-*

* Present in *Harpes*.

pterida, *Pterygotus*, &c.). Two pairs of eyes (one, lateral and compound, the other, median and simple), the ambulatory appendages around the mouth, and the sword-like telson, are the points of resemblance between them. But there are many differences ; the chief ones among which are the want of the facial suture in the dorsal surface of the cephalothorax, and the fact that the appendages are divided into more than six segments in the Merostomata. The Merostomata resemble closely the Scorpionida, an order of the Arachnida. Hence we find a relation between *Limulus* and the Arachnida.

From early times the genetic relation between *Limulus* and the Arachnida has been maintained, and at present we do not doubt the reality of such a relationship; but whether *Limulus* ought to be classified among the Arachnida or among the Crustacea, or be made into an independent class is still an open question. In order to show at a glance in what points *Limulus* resembles, and in what points it differs from, the Crustacea on the one hand and the Arachnida on the other, I have introduced the table on the next page. I venture to think that there are some new points which have not been noticed by previous writers but which are nevertheless quite significant.

From the table it will be seen that *Limulus* differs in many points from both the Crustacea and the Arachnida. With the sole exception of the facial suture, there is no important point in which *Limulus* differs from both the Crustacea and the Arachnida. In those points in which *Limulus* differs from the Arachnida, it resembles the Crustacea, and where it differs from the Crustacea it resembles the Arachnida. Therefore it appears to me not advisable to place *Limulus* in either class, or to make it an appendix to either. On the whole it seems safe, or rather necessary, to make an independent class for *Limulus* and the Trilobita.

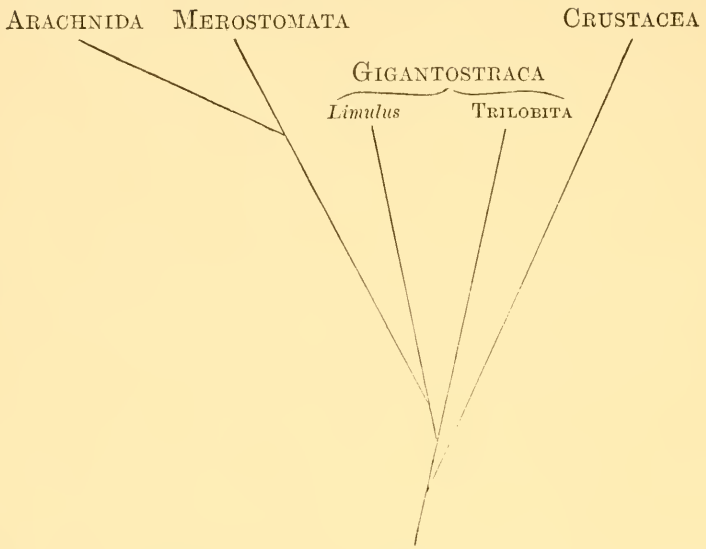
Hitherto the Merostomata have generally been considered to be

more nearly related to *Limulus* than the Trilobita are; but I venture to doubt the correctness of this view: my conclusions as set forth above point in just the opposite direction.

	ARACHNIDA	LIMULUS	CRUSTACEA
Lateral eyes	many, simple	two, compound	two, compound
Median eyes	two (paired)	two (paired)	one (unpaired)
The distal portion of the ambulatory appendage from the carpopodite consists of	four segments	three segments (in the last pair, four)	three segments
Yolk in the embryo remains long and abundant in	the posterior region of the body	the anterior region of the body	the anterior region of the body
Cœlomic cavity	one pair in every segment and enters into the appendage	does not enter into the appendage and is not developed in some segments.	does not enter into the appendage and is not developed in some segments
Malpighian tube	present	wanting	wanting
Brain and optic ganglia arise from	paired grooves in the paired epiblastic thickenings	paired grooves in the paired epiblastic thickenings	paired epiblastic thickenings
Nauplius stage	wanting	wanting	present
Breathe	in air	in water	most of them in water
Origins of mesoderm of the ventrum	two (in spiders)	two	one
Blood vessel ensheathes the nervous system	,,	,,	in most of them not
Entosternite	present	present	wanting
Facial suture	indistinct	distinct at the dorsal side	distinct at the margin

The name *Gigantostraca* may conveniently be retained for the new and somewhat restricted class containing *Limulus* and the Trilobita. The Merostomata excluded from the group ought, in my opinion, to be classified as an appendix to, or as an order of, the Arachnida.

The genealogical tree which I would construct is as follows:



What order of the Crustacea is most nearly related to the Gigantostraca I do not know, as the developmental history of different orders of the class is not yet well known.

I have already compared the eyes of *Limulus* with those of the Arachnida, and found that they are probably homologous with each other. But I do not know whether the eyes of *Limulus* are homologous with those of the Crustacea or not.

The homology between the pulmonary sac of the Arachnida and the lamelligerous gills of *Limulus* is most probable and is generally acknowledged. But as to the manner in which the former has been derived from the latter, whether by invagination or by subsidence, opinions of investigators do not agree. If a pulmonary sac of the Arachnida is formed by the invagination of a lamelligerous appendage of a *Limulus*-like ancestor, (1) the mouth of the invagination ought to look towards the head, (2) the gill lamellae ought to be formed on the posterior wall of the invagination, (3) new lamellae ought to be added ventral to those already formed, *i.e.*, the most dorsal gill lamellae must be formed first.

But none of these points so happen in the development of the pulmonary sac of the Arachnida. Hence I think the pulmonary sac of the Arachnida has been produced by the subsidence of the lamelligerous appendage of a *Limulus*-like ancestor.

The number and position of the eyes are exactly the same in *Limulus* and in the Chordata. The median eyes of *Limulus* are represented by the pineal eye of the Chordata, which is probably formed by the union of a pair of median eyes such as those in *Limulus*. The lateral eyes of *Limulus* are represented by the paired eyes in the Chordata. The paired eyes of the Chordata differ from the lateral eyes of *Limulus* by having their retinal portions inverted; but this is the effect of the closure of the medullary plate with the optic area into a tube. The retina of the paired eyes of the Chordata is also composed of ommatidia—a cone surrounded by many rods.

The lateral eyes of *Limulus* receive their nerves from the pre-oral cephalic lobe. Then the ancestral mouth of the Chordata must be searched for behind the optic chiasma, and within the ring of the nervous system. We have an invagination in the nervous system, which cannot be explained otherwise than by considering it as the degenerated stomodæum of the ancestor. It is the infundibulum. The view that the infundibulum is the remnant of the ancestral mouth is maintained by Cunningham, Patten, Gaskell, &c. The facts that the infundibulum is closely in contact with the anterior end of the mesenteron in the embryonic stage, and that it is behind the optic chiasma, favours this conclusion.

The origin of the mesoblast, separation of the nerve-cord from the epiblast, formation of the heart, the number and position of the eyes, the grooves in the brain, &c., make *Limulus* approach more closely to the Chordata than it was thought to do formerly, and accordingly make the Arthropoda more nearly related to the Chordata than to the Vermes.

Tokyo, June, 19, 1891.

Explanation of Figures.

List of Abbreviations.

I, II, III, &c.	Segments of the 1st, 2nd, 3rd, &c., appendages.
ao. a.	Aortic artery.
app.	Appendage.
br.	Brain.
C.	Cephalic lobe segment.
cox. gl.	Coxal gland.
d.	Dorsal side of the embryo.
d. g.	Dorsal groove of the lateral eye.
entost.	Entosternite.
ex. gr.	External groove of the brain.
flab.	Flabellum.
flab'.	Structure homodynamous with the flabellum.
g.	Ganglia.
g. lat. e.	Ganglia of the lateral eye.
g. med. e.	Ganglia of the median eye.
ht.	Heart.
int. gr.	Internal groove of the brain.
lat. e.	Lateral eye.
lat. gr. 1.	First lateral groove of the ventral plate.
lat. gr. 2.	Second lateral groove of the ventral plate.
lat. h.	Lateral hump.
mar. bd.	Marginal band.
m. e.	Epiblastic cells between lateral ganglia.
med. e.	Median eye.
med. l.	Median line of the embryo.
mes'.	Mesoblastic cells derived from the yolk-hypoblast.
n.	Nerve.
oeso.	Œsophagus.
op.	Operculum.
ost.	Ostia of the dorsal circulatory vessel.
pl.	Pleura.
prim. gr.	Primitive groove.
prim. str.	Primitive streak.
prov.	Proventriculus.
st. a.	Sternal artery.
stom.	Stomodæum.
v.	Ventral side of the embryo.
v. g.	Ventral groove of the lateral eye.

Plate V.

Fig. 1. Peculiar markings on the shore, showing the place where eggs were laid.

Fig. 2. Surface view of an egg which has many irregular fissures (5 days after fertilization).

Fig. 3. Surface view of an egg with the blastodermic thickening (10 days after fertilization).

Fig. 4. Surface view of an egg, at the beginning of the metamerism (13 days after fertilization).

Fig. 5. Ventral surface view of an egg, 14 days after fertilization.

Fig. 6. The same as above, a little more advanced.

Fig. 7. Ventral surface view of an egg, 15 days after fertilization.

Fig. 8. Surface view of the ventral plate of an egg, at the commencement of the appearance of appendages (16 days after fertilization).

Fig. 9. The same as above, a little more advanced.

Fig. 10. Surface view of the ventral plate of an egg, 17 days after fertilization.

Fig. 11. Two specimens of the chorion, broken up by growth.

Plate VI.

Figs. 12–14. Three successive stages in the development of the ventral plate. The nervous system is marked dark red, while the mesoblastic somites are marked blue and the cavities in them light blue. Fig. 12, 19 days old; fig. 13, 21 days; fig. 14, 25 days, about × 30.

Fig. 15. Side view of an embryo, about 24 days old.

Fig. 16. Dorsal view of an embryo, about 25 days old.

Fig. 17. Dorsal view of an embryo of the trilobite stage, showing the formation of the dorsal circulatory system.

Fig. 18. Heart of *Limulus Polyphemus*, after A. Milne Edwards (much reduced).

Fig. 19. Coxal gland of an embryo, about 27 days old, constructed from sections. a. Ventral view. b. Side view.

Fig. 20. Coxal gland of an embryo, about 30 days old, constructed from sections. a. Ventral view. b. Side view.

Plate VII.

Fig. 21. Transverse section through the blastodermic thickening of an egg, 10 days old, shown in fig. 3. 2C.

Fig. 22. Transverse section through the blastodermic thickening of an egg, 11 days old. 2B.

Fig. 23. Transverse section through the rudimentary ventral plate of an egg, 13 days old, showing the separation of the blastodermic thickening into epiblast and mesoblast. 2B.

Fig. 24. Portion of a section, similar as above, showing the columnar epiblast cells and a mesoblast cell with 2 very large nuclei. 2D.

Fig. 25. Transverse section through the cephalic lobe of an embryo, 14 days old (fig. 5), showing the separation of the mesoblast into 2 lateral bands. 2B.

Fig. 26. Longitudinal section through the ventral plate of an embryo, 16 days old (fig. 8), showing the appearance of the cœlomic cavity in the 5th segment. 2B.

Fig. 27. Transverse section through the primitive streak of an embryo, 16 days old (figs. 8,9), showing the formation of the mesoblast cells in the posterior part of the ventral plate. 2D.

Figs. 28–31. Transverse sections through the ventral plate of an embryo, 17 days old (fig. 10). 2B.

Fig. 32. Transverse section through the posterior part of the ventral plate of an embryo, about 20 days old (fig. 14). 2B.

Fig. 33. Transverse section of the anterior part of an embryo, shown in fig. 12. 2B.

Plate VIII.

Figs. 34, 35. Horizontal sections of the cephalic region of an embryo, shown in fig. 12. 2C.

Figs. 36, 37. Horizontal sections of the cephalic region of an embryo, shown in fig. 13. 2C.

Fig. 38. Horizontal section of the cephalic region of an embryo, shown in fig. 14. 2C.

Plate IX.

Fig. 39. Portion of a transverse section of an embryo at the stage of fig. 12. 2C.

Fig. 40. Portion of a transverse section of an embryo, shown in fig. 13. 2C.

Fig. 41. Dorsal portion of a transverse section of an embryo, showing the columnar cells of the dorsum. 2D.

Fig. 42. Portion of a transverse section of an embryo, shown in fig. 10, showing the prominent lateral hump. 2D.

Figs. 43, 44. Dorsal, median portions of transverse sections of an embryo, at about the stage of fig. 16, showing the formation of the heart. 2D.

Fig. 45. Portion of a transverse section of an embryo, represented in fig. 17. 2C.

Fig. 46. Anterior portion of a longitudinal section, showing the peculiar cell group of the brain. 2D.

Fig. 47. Portion of a transverse section of an embryo, shown in fig. 13, through the fifth ganglia. 1C.

Fig. 48. The same as above, cut through the sixth ganglia. 1C.

Fig. 49. Longitudinal section of the second abdominal appendage, before the formation of the gill-lamellae. 2D.

Plate X.

Fig. 50. Median longitudinal section of an embryo at the beginning of the trilobite stage. 2aa.

Figs. 51, 52. Horizontal sections of an embryo in the same stage as above. 2aa.

Fig. 53. Horizontal section of the abdomen of an embryo of the trilobite stage. 2aa.

Figs. 54, 55. Transverse sections through the abdomen of an embryo, a little more advanced than the one above mentioned. 2aa.

Figs. 56, 57. Longitudinal sections of an embryo in the stage of fig. 17. 2aa.

Plate XI.

Fig. 58. Portion of a transverse section of an embryo, shown in fig. 14, through the coxopodite of the 5th appendage. 2C.

Fig. 59. Transverse section (a little oblique) of the cephalic region of an embryo, shown in fig. 12. 2B.

Fig. 60. Portion of a transverse section of an embryo, shown in fig. 13, through

the lateral eye. 2D.

Fig. 61. Lateral portion of a transverse section of an embryo, a little before the stage of fig. 15, through the lateral eye. 2D.

Fig. 62. Transverse section of the lateral eye of an embryo, shown in fig. 17. 2D.

Fig. 63. Two consecutive transverse sections of the anterior end of the lateral eye. 4B.

Fig. 64. Transverse section of the lateral eye of an embryo of the trilobite stage. 2D.

Fig. 65. Cross section of three ommatidia of the lateral eye of an embryo of the trilobite stage. 2F.

Fig. 66. Longitudinal section of the same. 2F.

Fig. 67. Longitudinal section of the median eye of an embryo, at about the stage of fig. 56. 2D.

Fig. 68. Portion of a longitudinal section of an embryo, shown in fig. 15. 2C.

Fig. 69. Diagrammatic representations of the anterior portion of the nervous system of an embryo of the trilobite stage. a. Frontal view. b. Side view of the right half.

On the Lateral Eyes of Spiders.[1]

by

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In order to compare *Limulus* and spiders with respect to the development of their eyes, I re-examined my sections and found that I had overlooked in my recent paper, a very important stage in the development of the lateral eyes of spiders,* so that my views on this point were in part incorrect. This obliges me to write out briefly the new conclusion I have arrived at.

All the lateral eyes of spiders, generally three pairs, arise from a *common* thickening of the epiblast on each side at the posterior external corner of the lateral vesicle before it is completely cut off from the general epiblast—at about the stage of the reversion of the embryo. The thickening is slightly *invaginated* and consists of cells arranged in many irregular rows (fig. A).

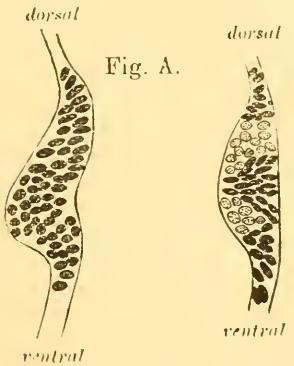

Fig. A. Fig. B.

Longitudinal sections through the "optic area" of the lateral eyes. Fig. B shows the "anterior lateral eye" and "posterior lateral eye" only. Zeiss 2 × D.

After the process of the reversion of the embryo has greatly advanced, the invagination disap-

1. This article was published in the Zoologischer Anzeiger No. 376 of Nov. 2 1891.

* *On the Development of Araneina.* This Journal. Vol. IV.

pears, and the epiblastic thickening above the lateral vesicle, which latter is by this time separated from the general epiblast becomes flat.

When the reversion of the embryo is almost over, a differentiation occurs among the nuclei of the epiblastic thickening. At three places in the thickening, nuclei become a little larger, and stain slightly less than those which are found elsewhere, and which are pressed together and are of a long ellipsoidal shape (fig. B).

These three groups of larger nuclei form the retinal portion of the three lateral eyes. They are spindle-shaped or rather wedge-shaped, narrower towards the exterior surface. Later they are separated from the surrounding nuclei at the narrower end by a ring-like furrow, peculiar to the lateral eyes, and the surrounding nuclei grow and meet together over the retinal portion, forming a layer of cells—the vitreous body.

The lateral eyes receive their nerves from a portion of the brain, formed by the lateral vesicle. Thus the latter is the optic ganglion, formed from an invagination, independently of the semicircular cephalic groove which gives rise to the brain proper.

The common epiblastic thickening of the lateral eyes of spiders is most probably homologous with the epiblastic thickening of the lateral compound eyes of *Limulus*, as its position is just the same and the invagination is similarly produced in both cases. Then, are the peculiar groups of larger nuclei of spiders homologous with the ommatidia of *Limulus?* I am inclined to believe that such is the case and that *the lateral eyes of spiders are separated, enlarged, and modified ommatidia of a compound eye of their ancestor.*

In Pl. IV, illustrating Parker's paper "The Eyes in Scorpions," we distinctly see that all the lateral eyes of the scorpion also arise from a common thickening of the epiblast. Thus we see that the occurrence of this interesting phenomenon is not confined to spiders but is found in

an allied order, Scorpionidea. Parker, however does not seem to consider this interesting fact as of much value, if he has not indeed overlooked it.

Lankester and Bourne* arrived at the same conclusion as I have done, from a study of the structure of the eyes of the adult *Limulus* and of *Scorpio*; but they wanted the embryological proof. Since they wrote much work has been done on the development of spiders, scorpions and *Limulus*: but no one till now has confirmed their conclusion.

The facts that the number and the relative position of the simple eyes of spiders and scorpions are very variable and that the eyes are placed more closely together in the embryonic than in later stages, speak in favour of our conclusion.

The separation and modification of the ommatidia of a compound eye into simple eyes are probably the effects of the change of the animal's habit—from that of wandering about in pursuit of prey to that of lying in wait for it.

The lateral eyes of spiders were called "Augen mit präbacillären Kern" by Graber, and "Nebenaugen" by Bertkau; but as they are homologous as a whole with the lateral eyes of scorpions and with the lateral compound eyes of *Limulus*, I propose to call them *lateral eyes* as I have done in this paper.

* Lankester and Bourne—*The Minute Structure of the Lateral and the Central Eyes of Scorpio and of Limulus.* Quart. Jour. Mic. Sc. XXIII.

Notes on a Collection of Birds from Tsushima.

by

I. Ijima.

Rigakushi, Ph. D., Rigakuhakushi.

With plate XII.

The interest attached to the island of Tsushima,* as one of the links connecting the Japanese Islands with the continent, led us to send Messrs. Namiye and Tsuchida, Assistants in the Zoological Laboratory, Science College, to make a general reconnaissance of its fauna. They collected specimens at several places on the island, altogether from Febr. 19th to April 7th, 1891, but of that time, short as it was, they could devote only a part to the work of the ornithological collection. Nevertheless, they succeeded in acquiring 136 skins of birds referable to some 48 species, a number which well attests the zeal of the collectors. It is upon these specimens that I now propose to make notes.

* Tsushima lies in the Straits of Corea, between Kiushiu and the Corean peninsula. Although it had been but imperfectly explored by zoologists, we had long known of the existence there of a species of wild-cat found in no other of the Japanese islands, and of a wood-pecker, *Thriponax richardsi*, considered to be peculiar to that island. The occurrence there of the Chinese Ring-necked Pheasant, *Phasianus torquatus*, not found on any of the main islands of Japan, has also been recorded, but this I believe is to be regarded as an element introduced from Corea by human agency.

1. **Merula fuscata**, (Pall.)

Jap. names : Tsugumi ; Chōma.

This species was found in great numbers on open paddy-fields. They were probably on migration. Eight specimens, dating Febr. 22nd to March 7th, were obtained at four different localities.

A specimen was also brought home from the island of Iki, between Tsushima and Kiushiu.

2. **Merula naumanni** (T.)

Hachi'ō-tsugumi : Akajinai.

This species, which but rarely straggles to the north-eastern portion of Hondo, seems to be a common visitor to Tsushima. Three specimens, all males (dating Febr. 22nd to March 6th), were obtained. They were found mixed in flocks of the above species. According to the report of Taczanowski (*Proc. Zool. Soc.*, 1888, p. 463) *M. naumanni* should also be common in Corea during the time of migrations.

3. **Merula pallida** (Gm.)

Shirohara : Yabutsugumi.

Numerous in bushes. Four specimens obtained, Febr. 19th to March 6th.

4. **Monticola solitaria** (Müll.)

Iso-hiyodori.

A female and two males were collected at Wani-ura at the northern extremity of the island.

5. Tarsiger cyanurus (Pall.)

Ruribitaki.

This bird was very abundantly met with. Eight specimens were obtained at Izuhara and vicinity on Febr. 19th and 21st.

A female specimen of *Ruticilla aurorea* was obtained on the island of Iki. This species undoubtedly occurs also on Tsushima.

6. Hypsipetes amaurotis (T.)

Hiyodori.

This species was one of the commonest birds of the island. Fifteen specimens obtained at different localities. In Tsushima as in Hondo, this bird has the habit of frequenting the blossoms of *Camellia japonica*. All the specimens from Tsushima have more or less pollen-powder, undoubtedly of the above-mentioned tree, attached to feathers at the base of bill. Mr. Namiye observed at Tsushima that the same tree is a favourite resort of *Mustela melampus* during night or in early morning. Anatomical examination of this mammal shot down from that tree, invariably showed him no solid contents in the stomach. On the other hand, he found that the half-open and up-turned corolla of *Camellia* contains drops of nectar, much sought after by children. I share with him in the belief that the *Mustela* as well as the Brown-eared Bulbul seeks that fluid instead of feeding on pollen.

On some of the specimens of *Hypsipetes amaurotis* from Tsushima, I notice the jugulum rather distinctly traversed by a band of pale-chestnut joining the dark chestnut patches on the sides of the head. It is caused by the apical half of the jugular feathers being suffused with that colour, which gradually fades away into the whitish of the attenuated end. The latter is usually found more or less abraded. The band is by no means equally pronounced in all

specimens and, where very faint, might easily be overlooked. Bringing together Hondo specimens (obtained in winter) for comparison's sake, I find similar colouring of the jugular feathers ; in at least three out of ten specimens the jugular band is as marked as in the Tsushima specimen which first attracted my attention to the matter. Possibly the deeper or fainter tone of chestnut on the jugular feathers is merely a matter of age. Even when very prominent, the ruddy area is so inextensive as to exclude the idea of directly linking the Tsushima birds with *H. squamiceps* of the Bonin Islands or with *H. pryeri* of the Loo-choos. In size the Tsushima specimens are as variable as Hondo-birds, and in their average I see no appreciable difference from the latter. The measurements of Tsushima specimens are appended below :

Museum number	Sex.	Length of wing.	Length of tail.	Tarsus	Middle toe with claw	Exposed culmen	Remarks.
1697	♀	120 mm.	112 mm.	21 mm.	21 mm.	21 mm.	*
1698	♀	126 „	116 „	23 „	23 „	22½ „	*
1699	♀	124 „	114 „	22 „	23 „	25 „	Scarcely any trace of ruddiness on jugular feathers.
1700	♂	131 „	118 „	23 „	23 „	25 „	*
1701	♂	130 „	122 „	22 „	23 „	24 „	*
1702	♀	126 „	112 „	23 „	22 „	23 „	The pale chestnut of jugular feathers rather prominent.
1703	♀	122 „	112 „	22 „	23 „	23½ „	*
1704	♂	130 „	119 „	23 „	22 „	25 „	*
1705	♂	133 „	123 „	23½ „	23 „	26 „	*
1706	♂	132 „	122 „	22 „	23 „	25 „	The pale chestnut of jugular feathers rather prominent.
1707	♂	118 „	105 „	22½ „	24 „	23 „	*
1708	♂	132 „	123 „	23½ „	23 „	25 „	*
1709	—	128 „	115 „	22 „	23 „	25 „	*
1710	♀	123 „	115 „	25 „	22 „	22 „	
1711	♂	132 „	117 „	25 „	22 „	23 „	

* Jugular feathers suffused with pale chestnut in varying degrees.

Messrs Namiye and Tsuchida also obtained two specimens of this species on the island of Iki, between Tsushima and Kiushiu. Both of these are much suffused with ruddy colour on the jugulum. The collectors do not remember to have noticed any difference in the screeching cry between the Tsushima and the Hondo Brown-eared Bulbuls.

7. **Zosterops japonica**, T. & S.

Mejiro.

This species is reported to be common on the island. It frequents *Camellia japonica* like *Hypsipetes amaurotis*. The two specimens brought back present the following measurements:

Mus. No.	Sex.	Wing.	Tail.	Tarsus.	Middle toe with claw	Exposed culmen
1749.	ad. ♂	59½ mm.	44 mm.	18 mm.	14 mm.	13 mm.
1750.	ad. ♂	60 „	——	18 „	14 „	12½ „

Both have the bill perceptibly stouter and longer than average Hondo-specimens, in which the exposed culmen measures 10—11 mm. The breast and flanks are somewhat less rufous than in many Hondo-specimens, others of which however match exactly in this respect with the two Tsushima skins now before me. Whether the latter represent a local race, perhaps intermediate between typical *Z. japonica* and *Z. stejnegeri*, I am not prepared to say.

8. **Cettia cantillans** (T. & S.)

Ko-uguisu.

A single female specimen was brought home. The wing measures only 55 mm., on which account I refer it to this species.

The collectors have very often heard the notes of this or the larger species (*C. cantans*). I would here remark that the distinctness of these two forms is exceedingly doubtful.

9. **Regulus cristatus orientalis**, Seeb.

= **R. japonicus**, Bp.

Kiku-itadaki.

This is said to be not uncommon on the island. A single specimen, a female, was obtained Febr. 28th.

10. **Parus minor**, T. & S.

Shijiukara.

This species was found common in pine-forests. A single female specimen was secured on Febr. 19th.

11. **Parus varius**, T. & S.

Yamagara.

Common in bushes. Seven specimens, all males, were obtained on Febr. 21st and March 2nd.

12. **Corvus macrorhynchus**, Wagl.

Hashibutogarasu.

The collectors brought home two specimens of the Oriental Raven. In gloss of plumage and in having grey bases to feathers, they agree perfectly with the two races known to occur in Japan, *viz.*, *C. macrorhynchus japonensis* of Hondo and *C. macrorhynchus levaillanti* of Loo-choo. In size of body they are decidedly smaller than the former, approaching the latter. The measurements are as follows:

Mus. No.	Locality	Date	Sex	Wing	Tail-feather	Tarsus	Middle toe with claw	Bill in front of the nostril	Height of upper mandible
1811	Tsushima	——	♀	316 mm.	204 mm.	57 mm.	53 mm.	41 mm.	16 mm.
1812	„	Febr. 23rd.	♂	318 „	204 „	57 „	54 „	39 „	18 „

For sake of comparison, I append below measurements of the two races just mentioned.

C. macrorhynchus japonensis.

Mus. No.	Locality	Date	Sex.	Wing	Tail-feather	Tarsus	Middle toe with claw	Bill in front of the nostril	Height of upper mandible
143	Tokyo	Nov. 28th 1883	ad. ♂	349 mm.	227 mm.	63 mm.	55 mm.	41 mm.	18 mm.
1495	Suka-gawa	Jan. 1st 1891	ad. —	340 „	216 „	60 „	53 „	43 „	17½ mm.

C. macrorhynchus levaillanti.

Imp. Mus., Tokyo	Loo-choo	March 13th. 1886	ad. ♀	320 mm.	210 mm.	53 mm.	50 mm.	37 mm.	15 mm.

In the above measurements, the height of the upper mandible was taken by placing one end of a divider on the cutting edge and the other on the culmen across the centre of nostril.

Of the two specimens from Tsushima, one (namely No. 1811) has the bill almost as slender as the specimen of *C. macrorhynchus levaillanti* from Loo-choo with which I have compared it. With regard to the other specimen (No. 1812), it is to be stated that the bill is as thick as in *C. macrorhynchus japonensis*, although in other respects it agrees well with No. 1811. I notice however that the curvature of the culmen is slightly but perceptibly less arched than in average specimens of the Hondo-race. Whether the indicated characters are due simply to immaturity or are to be regarded as pointing to the

Loo-choo race, my knowledge does not reach far enough to decide. As it is known that the two races intergrade, it is possible that I have intermediate forms before me.

The collectors very often noticed the thick-billed raven both in towns and on fields, associated with the following species.

13. **Corvus corone**, L.

Hashibosogarasu.

This should be quite common on Tsushima. A single immature specimen (No. 1813) was brought home.

14. **Garrulus japonicus**, Bp.

Kakesu, Kashidori.

The collectors have met with this species on two occasions, Febr. 21st and March 6th. Three specimens were obtained.

15. **Lanius bucephalus**, T. & S.

Mozu.

A male specimen seen only once and obtained.

16. **Motacilla lugens**, Kittl.

Haku-sekirei.

This was found not so common as in Tokyō. Two specimens, an adult and an immature male, were brought back.

17. **Motacilla leucopsis**, Gld.

Hōjiro-sekirei.

This species, which occurs also in Corea (Taczanowski, *Proc. Zool. Soc.*, 1888, p. 464), is an addition to the ornis of the Japanese

Empire. Although I have no continental specimen to compare with, I do not hesitate in the least to consider the specimen now before me as of this species, as it matches perfectly with Mr. Sharpe's description in *Brit. Mus. Catalogue*, vol. X. It is a male adult in full plumage (Mus. No. 1746). The black of the throat is a large patch and the base of the secondaries is white on both webs. Dimensions: Wing 90 mm.; Tail-feather 89 mm.; Tarsus 24 mm.; Middle toe with claw 17 mm.; Bill in front of nostril 10½ mm.

The specimen was shot March 24th on Mitsu-shima, a group of rocks at the northern end of Tsushima. The collectors looked on it as an old example of *M. lugens;* but it is at once distinguishable by the absence of black eye-stripe.

18. **Anthus spinoletta japonicus**, (T. & S.)

Tahibari.

A specimen in much abraded plumage was secured, Febr. 20th. Flocks of this bird were observed several times.

19. **Fringilla sinica**, L.

Ko-kawarahiwa.

Very common on the island, but only a single male specimen was obtained.

20. **Passer montanus**, (L.)

Suzume.

Very abundant near houses as in Hondo. A specimen was brought home.

21. Emberiza ciopsis, Bp.

Hōjiro.

? Emberiza castaneiceps, Moore.

Chōsen-Hōjiro.

E. castaneiceps, originally known from China, also occurs in Corea (Giglioli and Salvadori, *Proc. Zool. Soc.*, 1887, p. 582; Taczanowski, *ibid.*, 1888, p. 465.) On the main islands of Japan it is represented by *E. ciopsis*, which, so far as I am aware, differs from the Chinese form only in the males having the ear-coverts black (summer plumage), or almost black with a slight suffusion of russet (winter plumage), instead of deep chestnut always. In what points the females of the two species differ, I do not know.

Messrs. Namiye and Tsuchida collected on Tsushima six specimens of Bunting, all in winter plumage. The following is the list :

Mus. No.	Locality	Date	Sex	Wing	Tail-feather	Tarsus	Middle toe with claw	Exposed culmen
1751	Tsushima	March 16th 1891	ad. ♂	74 mm.	71 mm.	19 mm.	18 mm.	10 mm.
1752	„	„ 3rd „	„ „	73 „	72 „	18 „	20 „	10½ „
1753	„	Febr. 19th „	„ „	74 „	70 „	18½ „	19 „	11 „
1754	„	March 2nd „	„ „	73 „	69 „	19 „	18 „	10 „
1755	„	„ 19th „	„ ♀	71 „	68 „	19 „	19 „	10 „
1756	„	——	„ ♂	77 „	72 „	20 „	20 „	10 „

Of the five males, one (No. 1756) was presented to Canon Tristram, so that I have now four males before me. Minute comparison of these with winter specimens of *E. ciopsis* collected on Hondō, shows a close agreement in all respects except in the colour of the ear-coverts. Namely, two specimens (Nos. 1753 and 1754) have the

blackish auriculars slightly more suffused with russet or chestnut than in most Hondō specimens; but then Hondō specimens that match completely in this respect, are not wanting. In the third Tsushima specimen (No. 1752), the auriculars bear a russet tone to such a degree as is never known in *E. ciopsis* of Hondo. The fourth Tsushima specimen (1751) has the auriculars a shade more russet; I would simply call it russet-brown or deep chestnut. Unfortunately I have no specimen of *E. castaneiceps* to compare it with. Perhaps the two forms are to be considered as intergrading with each other on the island of Tsushima. It will be interesting to know whether in summer the ear-coverts of the Tsushima Bunting turn black or remain suffused with chestnut more or less.

According to Mr. Sharpe (*Brit. Mus. Catalogue*, Vol. XII, p. 544), *E. castaneiceps* should be wanting the tiny black spot on the chin; but that this is not always the case, has been shown by Canon Tristram (*Ibis*, 1889, p. 294). Of the four male Tsushima skins now before me, three have a distinct chin-spot, the fourth (No. 1753) having that part destroyed by shot. In true *E. ciopsis* of Hondō, the chin-spot is mostly wanting; out of forty-two male skins that I examined, only six showed it with any distinctness. The single female skin (No. 1755) from Tsushima shows no trace of chin-spot, agreeing in all respects of coloration with females collected on Hondō.

In the amount of white on the outer tail-feathers, I see no appreciable difference between Tsushima and Hondō specimens.

Messrs. Namiye and Tsuchida also collected two male specimens on the island of Iki (Nos. 1824 & 1825). These have the ear-coverts agreeing well in colour with average Hondō specimens.

22. Emberiza personata, T.

Awoji.

A male specimen obtained March 2nd measures: Wing 70 mm.; Tail-feather 70 mm.; Tarsus 21 mm.; Middle toe with claw 20½ mm.; Exposed culmen 10½ mm. It differs considerably in colouring from adult specimens collected on Hondō. The lores are more black; the head, nape, hind-neck, and sides of head and neck are less olive-green but more ashy-grey; the slight streak above the ear-coverts is whitish instead of sulphur-yellow; the cheek-stripe and under parts from throat to under tail-coverts, whitish, washed with very pale sulphur-yellow, yellower on breast and sides of abdomen. In fact, the yellow of the plumage is paler than I have ever seen on Hondo specimens; otherwise it agrees well with the latter. Young, in first winter plumage?

A male specimen of *Emberiza variabilis* in immature plumage was brought home from the island of Iki. This species has, as far as I know, never yet been recorded from Corea.

23. Emberiza elegans, T.

Miyama-hōjiro.

Common on the island. Five specimens obtained at three different localities, March 2nd to 19th.

24. Thriponax richardsi, (Tristram.)

Amanojakuma (Pl. XII)

This is undoubtedly the most interesting species among the present collection. Only a single female specimen hitherto existed in the possession of Canon Tristram, the original describer of the species (*Proc. Zool. Soc.*, 1879, p. 386). Messrs Namiye and Tsuchida had

succeeded in securing three magnificent specimens during their stay on Tsushima. The following is their table of measurements.

Mus. No.	Locality	Date	Sex	Total Length	Stretch of Wings	Wing	Tail-feather	Tarsus	Anterior external toe without claw	Bill from frontal feathers
1784	Kune-inaka	March 8th, 1891.	Ad. ♀	524 mm.	799 mm.	255 mm.	186 mm.	35 mm.	27½ mm.	39 mm.
1785	Niimura	„ 16th „	Ad. ♀	502 mm.	773 mm.	250 mm.	190 mm.	34 mm.	26½ mm.	35 mm.
1786	Kune-inaka	„ 13th „	Ad. ♀	488 mm.	774 mm.	247 mm.	180 mm.	34 mm.	26 mm.	37 mm.

In the above measurements, the total length and stretch of wings were taken by the collectors from the fresh specimens. The colour of the iris should be *clear yellow*, not black as represented in Canon Tristram's figure (*loc. cit.* Pl. XXXI), or as quoted by Mr. Hargitt (*Brit. Mus. Cat.*, vol. XVIII. p. 506) from Richards, the collector of the type specimen. Bill horny black, each mandible with a small dull-whitish spot at the tip of cutting edge; tarsus and toes black; claws horny-black.

The description of adult female plumage as given by Mr. Hargitt (*loc. cit.*) from the type specimen tallies well with the two female skins now before me. The male agrees with the female in all respects except in having the same sexual distinction of red on the head possessed by its congenors, as had been foretold by Canon Tristram twelve years ago. As I presume that specimens of this species will continue to be rare among collections, I insert the following description of the plumage.

Adult male. *The prevailing colour is black or deep brownish-black, with exceptions to be mentioned in the sequel. Feathers of this colour have generally dark grey bases, and those of the hind neck, the upper*

back, the side of neck, the ear-coverts, the smaller wing-coverts, the lower throat and the upper breast show a varying degree of greenish gloss. On the upper back this is the most intense, and here as on the upper breast, it is seen as restricted to the rather well-defined, narrow marginal zone of feathers. Forehead, crown and elongated occipital crest bright crimson, the feathers having the basal part white and the extreme base dark grey. Broad malar stripe also crimson, but somewhat duller, each feather with a small whitish patch near the base which is dark grey. Nasal bristles black with smoky-brown bases. Chin and upper throat dark smoky-grey, gradually passing into the brownish-black with greenish-black gloss of the lower throat. The latter is finely streaked with short white lines, caused by the marginal tips of barbs being of that colour. A few similar streaks also found on post-malar feathers and a patch of them just behind the ear-coverts. Lower back and rump silky white, the exposed parts of feathers bearing a slight buffy tinge. A few feathers along the anterior border of this white area have more or less black on them, leaving the tips white: this can only be recognized by raising the feathers. Some few hindmost feathers of the lower rump have a black spot near the tip, varying in shape and size. The two central feathers of the upper tail-coverts are white with a large irregular spot of black on their apical portion: but when the feathers of the rump are not raised, they have the appearance of being black margined with white, as Mr. Hargitt observes. Six primaries (2nd to 7th) tipped with white, broadest on the 3rd, 4th and 5th primary, narrowest on the outer web of the 7th primary. Bases of all primaries and secondaries white with a slight tinge of yellow, the former only on the inner web (to the extent of about 18 mm. on the 1st and about 39 mm. on the 3rd primary): the latter on both webs (to the extent of 70–80 mm. on the inner web). Under wing-coverts mostly white with a yellowish tinge, some feathers near the edge of the wing being marked with varying amount of dark-brown, whereas the edge itself is black with greenish gloss. Axillaries, the entire sides of the body,

lower breast and upper abdomen, white with a slight yellowish or buffy tinge, the feathers having the extreme base dark-grey and the rest of basal portion silky white, assuming the above-mentioned tinge towards the exposed apical portion. The black feathers of the breast in close proximity to the white area are margined at the tip with buffy white. Lower abdominal feathers black and also margined with buffy white. Thigh-feathers with a large black area, presenting the appearance of being likewise black and margined with buffy white. Tibial feathers with a brownish-black marking, leaving the tips buffy-white and the basal parts whitish. Shafts of quills and of tail-feathers deep brownish-black.

Adult female. *Like the male in plumage, except that the head is entirely wanting in red. The feathers of the forehead, crown and occipital crest, as also of the malar region black with greenish gloss, the bases of feathers being dark grey. The greenish gloss of the upper back less intense than in the male. On one (No. 1786) of the two female skins, the short 1st primary is tipped with white, which is not the case on the other specimen; the six following primaries have always white tips as in the male.*

Of the habit of this species, and of other points concerning it, Messrs. Namiye and Tsuchida have kindly supplied me with materials for the following account.

On March 3rd, while passing through the deep forest of Tadera (about 15 miles to south-west of Izuhara), their attention was called to a strange piercing cry repeated a few times. Whence it emanated they could not tell, but imagined it was something like the shriek of some hawk's nestling. They waited for many minutes expecting to hear it once again, but in vain, and as no sign of any animal was discernible, they moved on, little thinking that they had just heard the long-sought *Thriponax richardsi*, as subsequent experience taught

them. A few days later, the bird itself was sighted for the first time at a village called Kune-inaka. Its cry is very characteristic and sounds somewhat like a prolonged "*Kyah*," alike in both sexes, very loud and heard for a great distance. This it repeats at intervals when on the wing as well as when climbing trees. Only in the latter case, each single "*Kyah*" is less prolonged. Besides the localities already mentioned, Messrs. Namiye and Tsuchida observed the bird also in the villages of Nii, Takeshiki, Mitsune, Sago, Sumo, &c. The specimens now in the Science College were shot, a pair at Kune-inaka and a second female at Nii, as will be seen from the list I have given. It is needless to say that the collectors made special endeavours to secure more specimens; but the wariness and the rapid movements of this bird made approach difficult and offered but little chances of a shot. The collectors' own observations and the answers of natives to inquiries made at various localities, prove that this fine woodpecker is by no means rare on Tsushima.

It finds its abode in dense, more or less extensive forests of tall pines, firs, cryptomerias, oaks, camphor-trees &c. Such a forest usually exists in valleys between hills, and is known to natives as *kuromi* (a dark place). The bird is never found in any numbers together; perhaps a pair is the utmost that a *kuromi* might harbour. Standing on the hill-top, one hears its peculiar cry and loud tappings at some considerable distance in the wooded valley beneath; he descends to the spot probably to find the bird gone, but some chippings of bark or wood strewn on the ground, and some bare places on the tree-stem above tells him the work it was recently busy at. Dead trees or branches naturally attract it when in search of food, and it is said that the bird goes regular rounds to its favourite trees every day. Should one of its trees be recognised, a collector would do well therefore to lie in ambush awaiting its arrival. Its

manner of flight is similar to that of other woodpeckers. The collectors have often marked the spot where the bird alighted, and on more than one occasion, they discovered it again *on the ground*, whence it climbed up a tree-trunk in the usual manner on their approach. I do not know whether a similar habit has ever been noticed in any other woodpecker.

The lower classes of the inhabitants of Tsushima hold this bird in some degree of religious awe. Some natives, as Mr. Namiye tells me, indulge in the superstition that when Buddha was in the process of creating man, a certain being called *ama-no-jakuma* pressed to have a certain part put on his forehead instead of much lower down on his body, and that that being was none else than the woodpecker in question. Hence the natives call this bird by that name. In ordinary Japanese, *ama-no-jaku* or *ama-no-jakuma* (evidently of buddhistic origin) is an appellation given to a cross-minded person.

25. Iyngipicus kisuki, (T.)

Kogera.

The typical form found on the Hondo also occurs on Tsushima. It was found to be very common. Six specimens were obtained between Febr. 19th and March 19th. They agree in colour and markings with specimens collected in Provinces Sagami and Hida.

26. Turtur gelastis, (T.)

Kijibato.

Abundant on the island. Nine specimens obtained. Length of wing, measured from the carpal joint, 183—197 mm.

27. **Phalacrocorax capillatus** (T. & S.)

Shimatsu.

Abundant on rocky shores. A specimen brought back.

28. **Ardea cinerea** L.

Aosagi.

An adult specimen brought home was the only individual that was seen on the island.

29. **Ardea jugularis**, Wagl.

Kurosagi.

On Mitsushima, a group of rocks at the northern end of Tsushima, the collectors have met with a flock of this bird already known to inhabit the island through the collections of Jouy and Ringer. It was exceedingly difficult to approach. Two fine specimens were secured.

Mus. No.	Locality & date	Sex	Wing	Tail-feather	Tarsus	Middle toe without claw.	Exposed culmen
1802	Mitsushima, March 25th 1891	Ad. ♀	290 mm.	112 mm.	80 mm.	58 mm.	83 mm.
1803	„ „ „ „	Ad. ♀	284 mm.	105 mm.	78 mm.	55 mm.	81 mm.

Total length and stretch of wings, as measured by the collectors, were 640 mm. and 1004 mm. in No. 1802, 627 mm. and 1041 mm. in No. 1803, respectively.

Dr. Stejneger has erected the grey Reef-heron of Tsushima into a distinct species, *Demiegretta ringeri*, for the reason that the top of head and the occipital crest are plumbious and lighter than the back (*Proc. U. S. Nat. Mus.*, 1887, p. 300). On the two specimens

before me, I fail to see this distinction; hence I have preferred to retain Wagler's name, as Mr. Seebohm does in his *Birds of the Japanese Empire*.

The white on the chin and throat seems to be quite variable in amount. On one specimen (No. 1802), it is a narrow interrupted streak, while on the other it is represented by a broad large patch on the upper throat followed by some three little spots.

The white form of Reef-heron was not observed.

30. **Anas formosa**, Georgi.

Aji-gamo; Tomoye-gamo.

A male specimen was shot at Niimura, March 16th.

31. **Anas galericulata**, L.

Oshidori.

A male specimen was obtained also at Niimura on the same day.

32. **Alca carbo**, (Pall.)

Keimafuri.

A specimen (sexed ♀ with query, Mus. No. 1787) was shot near Ōfunakoshi, March 27th. This was the only individual that the collectors have met with. It is in mature plumage with remiges and rectrices much abraded. Amongst other localities this species also occurs in Olga Bay (Giglioli & Salvadori, *Proc. Zool. Soc.*, 1887, p. 593).

33. **Alca antiqua**, Gm.

Umi-suzume.

On March 15th a specimen was shot at Sagamura. A few days

later five specimens were secured at Ina-ura. They were found in flocks.

34. Alca wumizusume, (T.)

Kammuri-umisuzume.

A pair of this rare bird was observed and one of them (Mus. No. 1783) secured, near Ōfuna-koshi, March 27th. The specimen obtained is a male and is furnished with a black occipital crest.

35. Fratercula monocerata, (Pall.)

Utō.

This species was common, mostly found in pairs. Five specimens were obtained at three or four points on the coast, March 18th. The horny projection above the nostrils is in various degrees of development, fully developed on only one specimen.

36. Larus cachinnans, Pall.

Seguro-kamome.

There are among the collection two specimens of Herring Gulls, which I refer to this species. The one, shot on Mitsushima, March 25th, is an adult, measuring 366 mm. in the wing (Mus. No. 1815). The other obtained at Azama, March 5th, is in young plumage, the wing measuring 347 mm. (Mus. No. 1817).

37. Larus vegae, (Palmén).

In 1890 I sent to Dr. Stejneger for identification three specimens of Herring Gull, collected at or near Tokyo. They were returned to me identified as *L. vegae*, a species originally discovered on the coast of Tchuski Land by the "*Vega*" expedition and described

by Palmén under the name of *L. argentatus*, var. *vegae* (*Bidrag Sibir. Ishafsk. Fogelfauna Vega-expedition**). The same species was also found by Dr. Bunge on the Liakoff Islands (*Beitr. z. Kenntn. d. Russ. Reiches u. d. angrenzenden Länder Asiens*†). Now, there is among the present collection from Tsushima an adult specimen of Herring Gull (Mus. No. 1816, obtained at Kuta, Febr. 20th) which agrees completely with those identified by Dr. Stejneger as *L. vegae*. It is very much like *L. cachinnans* but smaller. Total length 620 mm. (against 715 mm. of adult *L. cachinnans*, (Mus. No. 1815), wing 308 mm. (against 366 mm.), middle toe with claw 61 mm. (against 68 mm.), exposed culmen 50 mm. (against 61 mm.).

38. **Larus crassirostris**, Vieill.

Umi-neko.

Two adult specimens were obtained.

39. **Larus canus**, L.

Kamome.

A specimen in immature plumage obtained.

40. **Hæmatopus osculans**, Swinh.

Miyakodori.

Abundant on Mitsushima, at the northern extremity of Tsushima. Three specimens obtained.

The white on the outside web of the primaries appears on one specimen (Mus. No. 1799) on the fifth and on another on the sixth quill, while the third specimen (Mus. No. 1800) shows a mere streak of it on the fifth quill.

* † These works have remained inaccessible to me, and are known to me only through Mr. Seebohm's account in *Ibis*, 1888, p. 349.

41. **Numenius cyanopus,** Vieill.

Hōroku-shigi.

A specimen was once met with and secured, on the sea-shore at Kōura, March 14th. It is a female with the exposed culmen 182 mm. long.

42. **Totanus fuscus,** (L.)

Tsuru-shigi.

A female in winter plumage was shot at Nii-mura, March 16th. That was the only time that this species was observed.

43. **Totanus glareola,** (L.)

Takabu-shigi.

A female was shot at Komoda, April 1st.

44. **Totanus hypoleucus,** (L.)

Mushibami-shigi.

A male obtained at Wani-ura, March 23rd.

45. **Colymbus arcticus,** L.

Ōhamu.

This species was often met with. A female in immature plumage was obtained. Above, brownish black, with few white spots on wing-coverts; below, white from the chin. Wing 182 mm., exposed culmen 50 mm.

46. **Podiceps rubricollis major**, T. & S.

Akanodo-kaitsumuri.

A fine pair was shot at Takeshiki, April 1st. Male (with chestnut throat) and female measure respectively 181 mm. and 180 mm. in wing, 50 mm. and 48 mm. in exposed culmen.

47. **Podiceps cornutus**, (Gm.)

Mimi-kaitsumuri.

A specimen was only once met with and obtained at Ina-ura, March 21st. It is a female in winter plumage. Wing 135 mm., exposed culmen 22 mm.

48. **Phasianus torquatus**, Gm.

Kōrai-kiji.

This is the common pheasant of Tsushima. *P. versicolor* is not found. Three males and one female were obtained at the villages of Uchiyama, Kune-inaka and Kuta. It is said to be most abundant at O-ura, a village not far from Izuhara. I have no continental specimens to compare with.

In an authentic manuscript work entitled "*Tsushima Kiryaku*" (津島紀略, treating of the geography, history, and natural products of Tsushima, written about 190 years ago) by Suyama, it is stated that pheasants are said to have been originally entirely wanting on the island and to have been first introduced in the middle ages on Unijima (at the northern extremity of Tsushima), whence they spread over the island proper. In another old manuscript "*Tsushima-Kiji*" (津島記事, a voluminous work of similar nature and equally authentic) by Hirayama, there stands a statement to the same effect only more definite.

In this connection I may mention that in the first named work I find a statement that the pheasants of Jishima (a small island off the coast of the province of Chikuzen, Kiushiu) are the same as those of Tsushima, as the result of transplantation from the latter island. Hino Kanroku in his ornithological work ("Yōkin-Monogatari," Narratives on Bird-keeping, written about 90 years ago) has also left a record of the Corean pheasant being introduced and made to thrive on some island off the western coast of Kiushiu (one of the Hirato group?).

On the Formation of the Germinal Layers in Petromyzon.

By

S. Hatta,

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With Plates XIII. and XIV.

In spite of the fact that several eminent investigators have been engaged in studying the embryology of the Cyclostomata, the development of Petromyzon presents as yet many points which remain obscure or which are stated in contradictory terms by different writers. The present investigation was undertaken to throw light on some of these points. It was carried on during the academic year of 1890–91 in the Zoological Laboratory of the Science College, under the supervision of Profs. K. Mitsukuri and I. Ijima. I may, in this place, be permitted to express my sincere thanks for the valuable advice which they have given during my work, and the kind manner in which they have forwarded my researches.

The species which I have studied is probably either *Petromyzon planeri* or a variety of it. The larger part of the materials used was collected and preserved by Prof. Mitsukuri during the month of February, 1890, in fresh-water streamlets between paddy-fields near the town

of Gifu, and my special thanks are due to him for placing them at my disposal. The other part of the materials was obtained by myself at the same place during the spring of the present year (1891). We wish to express our deep obligations to Mr. Nawa, the enthusiastic naturalist of Gifu, without whose aid we could not have succeeded in obtaining the objects of our search, and to the authorities of the Middle, and of the Normal, Schools of that town for affording us laboratory accommodation.

The eggs and larvæ were hardened partly in Kleinenberg's picro-sulphuric acid, and partly in corrosive sublimate. A few larvæ were also killed in Flemming's solution. The sublimate specimens gave the best results, although good sections were obtained in all cases. Acids, on the whole, had the effect of making yolk-granules highly refractive, and thus greatly increased the difficulties of observation.

As to the staining fluids, picro-carmine gave by far the most satisfactory results. This, being the nuclear stain and not affecting yolk granules, made observation comparatively easy. Other colouring fluids like borax-carmine or haematoxylin (of Kleinenberg as well as of Böhmer) stained diffusely both the protoplasm and the nuclei, and above all, were most unsuited for my purpose from the fact that they stained yolk granules the deepest.

The age of the eggs and of the larvæ was not determined by the actual time elapsed, but by their appearances as opaque objects and by their structure as shown by sections.

Care was taken to have sections of each stage made in several planes so as to enable us to obtain as accurate an idea as possible of it.

I shall give the results of my investigation under the following heads :—

1. The Gastrulation.
2. The Formation of the Mesoblast.

I. The Gastrulation.

My observations on segmenting eggs are too incomplete to enable me to make any definite statement in regard to the process. The earliest stage on which I wish to offer remarks is that of the oldest morula. When this is viewed as an opaque object, the animal pole and the vegetative pole can be externally distinguished: the former is whitish and somewhat translucent both in fresh and in hardened specimens, while the latter is opaque and of a pale yellow colour. A slight depression goes round the egg marking the boundary between these two portions.

In sections (fig. 1) the contrast of the two portions is well brought out. A spacious segmentation cavity is placed excentrically in the egg and occupies the whole interior of the animal pole. The cells forming the roof of this cavity are arranged in 2–4 layers and, compared with the cells of the opposite pole, are smaller, comparatively free from yolk granules, and have smaller nuclei which stain on the whole deeper. The cells forming the floor of the segmentation cavity are 7–8 deep, full of yolk-granules with other characters as indicated above. All the cells are polygonal in shape, evidently through mutual pressure.

The next step of development consists in the gradual thinning out of the roof of the segmentation cavity. Opinions differ in regard to the extent to which this process is carried before gastrulation sets in. According to Scott[1] and Shipley,[2] the roof of the cavity becomes one cell layered before the gastrulation begins. On the other hand,

1. W. B. Scott:—Beiträge zur Entwicklungsgeschichte der Petromyzon. Morph. Jahrb. Bd. VII.

2. A. E. Shipley:—On some points in the Development of *Petromyzon fluviatilis*. Quart. Journ. Micr. Sci., Vol. 27.

Kupffer[1] maintains that the process of invagination takes place, at the same time as the differentiation of the epiblast. He states further: "*Ehe der Vorgang der Blastodermbildung die Region der grössten Zellen am Gegenpol erreicht hat, erscheint bereits der Blastoporus. Das Blastulastadium is hier also verkürzt, die Bildung der Blastosphäre coincidirt mit dem Beginn der Gastrulation.*"

Although I can not be positive about this point, my observations tend to confirm the views of Kupffer. Among a number of sections belonging to these stages, I can not find a single one which has the roof of the segmentation cavity consisting of a single layer of cells. I have, however, one series in which I think the process of invagination is just ready to begin. I have figured a section of this series in fig. 2. H. XIII. It will be seen that in this egg a portion of the side wall of the segmentation cavity is thinned out into one layer of cells which have assumed a regular columnar shape. This is probably the point where invagination begins, and possibly corresponds with the differentiated region in fig. 10 of Kupffer's paper. The rest of the roof of the segmentation cavity is still two to three cells thick. I have also some eggs, in which, while the gastrulation is going on, the roof of the segmentation cavity is in some places one cell and in other places two cells thick. In such cases, wherever the roof consists of a single layer, the cells assume a columnar shape, different from the irregular polygonal shapes of earlier stages.

As to the manner in which the roof of the segmentation cavity thins out, previous writers seem to consider that it is brought about by the inner cells of the roof passing round to the sides and to the floor of the segmentation cavity, while the outermost layer of cells becomes the definitive epiblast. If the upper cells passed really to the sides and to the floor of the segmentation cavity, they ought to be

1. C. Kupffer:—Die Entwicklung von Petromyzon Planeri. Arch. f. Mikros. Anat. Bd. 35.

easily recognized in these parts, especially on the floor, as they are so markedly different from the cells of the vegetative pole. Any trace of such migration is however not to be found. I am strongly inclined to believe that the thinning out is brought about by the cells of different layers in the roof of the segmentation cavity wedging themselves in between one another, thus gradually reducing the number of layers. As this process of wedging in necessarily increases the superficial extension the cells are able to spread themselves to the invaginated tube as well as over the cells of the vegetative pole by epibole during the gastrulation. Hence the thinning out is continued and carried on at the time that the invagination is taking place. According to this view, the definitive epiblast is not formed necessarily by the cells which formed the outermost layer of the animal pole in earlier stages, but by those which were left after other cells have been invaginated.

The gastrulation now commences. Eggs undergoing this process show several marked changes even when viewed as opaque objects. In the first place they acquire the appearance of being solid and firm, no doubt in consequence of the obliteration of the segmentation cavity. They also decrease in their absolute size, as can be easily perceived by the naked eye. This must necessarily be the case when we remember that a large portion of the cells is invaginated into the inside of the egg. The shape of the egg also undergoes change. Instead of being almost spherical as hithertofore, they have become more or less elongated in the longitudinal axis of the future embryo. The anterior end can now be told from the posterior, as the former is rounded, while the latter is pointed. The dorsal surface can likewise be distinguished from the ventral, as the former shows a faint median ridge. Thus the egg assumes a distinct bilateral symmetry.

The internal changes accompanying these alterations in outward

appearance can be gathered from figs. 2, 3, and 4, Pl. XIII. As already stated, I am inclined to believe that fig. 2 shows the stage in which the invagination is just commencing. The cells where this process begins (*bp.* fig. 2) assume first of all a columnar shape, while the rest still remain materially unchanged. Once begun, the invagination progresses rapidly, the roof of the invaginated tube being formed by the cells coming from the animal pole, while its floor is furnished by the yolk cells. According to Shipley *(loc. cit.)* and Kupffer *(loc. cit.)*, the epiblast extends itself over the vegetative half of the egg by the conversion of the outermost row of yolk-cells into small columnar cells. This appears to me very doubtful. I think it more probable that the whole yolk-cells are bodily invaginated into the interior, *i. e.*, the point marked *x* in fig. 2 moves itself constantly towards the blastopore (*bp.*), so that the whole mass of yolk-cells is really pushed inside. According to this view, what was at first the external surface of the yolk-cell mass, becomes the floor of the invaginated tube. The segmentation-cavity is pushed forwards and early obliterated. This process is very much like that described by Hertwig[1] in Triton.

Fig. 4 represents a median sagittal section through an egg in which the invagination is almost completed. Fig. 3 is a transverse section of an egg a little younger. From these two sections some idea of the character and disposition of the cells forming the different layers can be easily formed. The roof of the mesenteron consists from the first of a single layer of columnar cells appressed against the under surface of the epiblast. I could not find throughout the entire extent of the invaginated tube, either in longitudinal or transverse series, any trace of cells interposed between the epiblast and hypoblast. I can not therefore accept Scott's invaginated mesoblast *(loc. cit.)*, nor can I find any trace of Kupffer's teloblast *(loc. cit.)*. The epiblast cells are also columnar

1. O. Hertwig:—Die Entwicklung des mittleren Keimblattes der Wirbelthiere. Jena, 1883.

but smaller and less tall than the hypoblast cells. Their cell-limits are also more distinct. The floor of the invaginated tube is formed by the upper row of yolk-cells, which have assumed a more or less columnar shape.

I wish to emphasize here the fact that the invaginated tube is not the same as the cavity of the future mesenteron. As the subsequent history shows, the whole mass of yolk-cells is absorbed with the exception of the outermost row lying immediately inside the epiblast. This latter becomes the definitive hypoblast (fig. 27 and fig. 19). Substantially the same thing has been shown by Scott (*l. c.* pp. 121–122), except that he regards the outermost row as destined to form the mesoblast, and the row next inside as forming the definitive hypoblast. When once we remember the above fact, one can easily perceive that what Kupffer believes to be the liver, in his figs. 27 and 28 (e), could not be such. This organ can not arise among the cells which are afterwards absorbed. I am inclined to think that what he calls the liver in his fig. 28 is the slit which arises between the main body of yolk-cells and its outermost row (cf. fig. 27).

II. The Formation of the Mesoblast.

At about the time when the gastrulation is almost completed, the egg undergoes one of the most important changes. To the two primary layers already dealt with, a third layer, the mesoblast, is added. The formation of this layer forms one of the most difficult subjects in the study of the embryology of *Petromyzon*. The alterations at first met with are altogether in the internal structure and can therefore be made out only in sections.

For the sake of convenience, I shall treat of the mesoblast under the following heads :—

A. The mesoblast in the neighbourhood of the blastopore (or the peristomal mesoblast of Rabl)

B. The mesoblast on each side of the dorsal axial organs (or the gastral mesoblast of Rabl)

C. The lateral and ventral portions of the mesoblast.

D. The metameric segmentation of the mesoblast.

A. *The mesoblast in the neighbourhood of the blastopore,* (or the *Peristomal Mesoblast* of Rabl) has never yet been described in Petromyzon by previous writers. I have, however, obtained sections from which it appears to me safe to conclude that mesoblast cells are budded out from all around the lip of the blastopore except the dorsal median point where the epiblast turns round to join the hypoblast. Fig. 5 represents the median sagittal section through an egg in which the gastrulation is already completed. In this figure, we find the floor of the invaginated tube formed, for a short distance from the blastoporic opening, of specially small cells. In continuation with this stretch of small cells, there is seen a wedge-shaped aggregation of similar small cells (*mes. p.*) extending ventrally between yolk-cells and the epiblast. It is marked off from the epiblast by a slit, while it lies in contact with yolk-cells and is marked off from these only by the small size of its constituent elements. In this mass, as well as in the stretch of small cells forming the floor of the invaginated tube, many karyokinetic figures are seen and testify to the fact that cells are very rapidly multiplying in this region. This mass is in my opinion the *peristomal mesoblast* (of Rabl).

Fig. 6 is a section from the same series passing through the lateral lip of the blastopore. Here we find a mass of similar small

cells, intervening between yolk cells and the epiblast, and stretching not only ventrally but also dorsally.

In embryos a little more advanced, these relations are much more clearly brought out. Fig. 7 is the median sagittal section of such an embryo. We again find the mass of small cells budded out from cells forming the floor of the invaginated tube for a short distance from the entrance.

Figs. 8–11 are a series of frontal sections from an embryo of about the same stage. Fig. 11 is the most posterior represented. It passes through the line *ab* in fig. 12. *i.e.*, just through the ventral lip of the blastopore. Here the mesoblastic mass which is distinguished by the small size of its cells and the intensive staining of their nuclei, is not paired but is continuous across, being interposed between the epiblast and the yolk-cells. The median portion of it is continuous with the epiblast and reminds us strongly of a section through the primitive streak of higher vertebrates, with which it is no doubt homologous. Fig. 10 shows the section passing through the line *cd* in fig. 12. The mesoblastic mass is on the whole paired but still continuous across the median line, as the section is not yet out of the region where mesoblast cells are being budded out from the floor of the invaginated tube. Fig. 9 is through the line *ef* in fig. 12. The mesoblastic mass is distinctly paired in this section, and passes in front into the gastral mesoblast in fig. 8. These facts are sufficient, I think, to justify my conclusion stated above, viz: that mesoblast cells are budded out from all around the lip of the blastopore except the dorsal median point.

B. *The gastral Mesoblast.* In the region of the body anterior to the blastoporic opening, the mesoblast arises as paired masses, one on each side of the chorda-*anlage*. The manner in which this mass is formed, is fundamentally the same throughout every portion where

it is found ; but in different regions, it presents some modifications. In the cephalo-cervical region, the process has retained best its primitive characteristics, while in the region of the trunk, it has become altered to a great degree, owing no doubt to the presence of the yolk-cells. On this account, we shall begin with the description of the mesoblast formation in the first named region, although in point of time it is formed latest in this part, as the formation of the gastral mesoblast proceeds from behind forwards.

As has been shown by Scott, (*l. c.*, Taf. VIII, fig. 10 b) the head is formed by the blind end of the invaginated tube protruding itself above the general surface of the egg. The head when first formed is thus a double-walled tube—the wall of the invaginated tube being enclosed by the epiblast. Fig. 19 is a section from near the blind end of the invaginated tube at the time when the head is ready to protrude. The lumen of the invaginated tube is here more expanded than further behind. Its roof is formed by a regular columnar epithelium in contact with the epiblast. Adapting itself to the slightly thickened medullary plate, the columnar epithelium is slightly bulged out downwards in the median line. This median part becomes afterwards the *chorda dorsalis* while the part immediately adjacent to it on each side forms the gastral mesoblast. Laterally, in continuation with the epithelium of the invaginated tube, the outermost row of the yolk-cells is arranging themselves into a regular epithelium. This, as the subsequent history shows, becomes the wall of the definitive gut, all the yolk-cells enclosed within this layer being eventually entirely absorbed (cf. fig. 27). This, in my opinion, corresponds with the layer marked *z* in fig. 11b. or that marked *Dm* in figs. 11a and 14 in Taf. VIII of Scott's paper (*loc. cit.*), although this writer regards the layer as giving rise to what he calls the "*Dotter-mesoderm*."

Fig. 20 shows a transverse or rather oblique section through the

head-region of an embryo a little more advanced. The neural cord has made a considerable progress and by its downward growth has pressed down the median portion of the gut-roof, *i. e.* the chorda-*anlage*. The latter is formed of a regular row of rather high columnar cells. Its lateral continuation on each side is reflected upwards and forms a deep diverticulum of the enteric cavity. This forcibly reminds us of the well known section of *Amphioxus* and the sequel shows that the resemblance is of a deep significance.

In fig. 21 taken from a somewhat advanced embryo, the development has advanced considerably. The chorda has now been completely isolated from its mother-layer, and lies firmly appressed with its upper margin against the neural cord, in which it causes a slight indentation. Owing to this isolation, the part of the gut-wall which was before situated immediately lateral to the chorda-*anlage*, has now slipped itself below the chorda, shutting the latter from the enteric cavity. Hypochordal cells (*hch*) are derived from this part. On each side of the median line, a conspicuous ridge or fold (*x*) of the outer wall of the enteric cavity has raised and pushed itself towards the median chorda-prominence, thus reducing the previously wide gut-diverticulum to a mere slit and by that process separating off a triangular mass of cells, the mesoblast (*mes. f.*).

In fig. 22, which represents a still more advanced stage, the mesoblast mass on each side has been entirely cut off from the wall of the enteric cavity. The constriction is solely brought about by the inward growth of the prominent ridge or fold of the outer wall of the enteric cavity previously referred to. The inner end of the ridge strikes itself against the mesoblastic layer opposite it, surrounding the chorda. It does not however coalesce with the same, but slips further downwards beneath the chorda and the hypochordal cells. At the same time, the two limbs of the prominent fold become separated; the

dorsal limb or the part that originally formed the wall of the gut-diverticulum becomes incorporated in the mesoblastic mass; the ventral half which was originally turned towards the definitive gut-cavity, loosens itself from the dorsal half and passes towards the median line beneath the chorda and hypochordal cells, until it meets and fuses with its fellow of the opposite side to form the definitive roof of the enteric cavity.

The process of mesoblast formation in the cephalo-cervical region as given above, is exactly like what we know to go on in *Amphioxus*. Calberla, Scott, and Shipley do not make any mention of such a primitive mode of the mesoblast formation in *Petromyzon*. Kupffer's description of the process in the head region accords well with my own observations, however with this great difference that according to him the chorda is cut off and completed long before the mesoblast is formed. That such is not the case, I have no doubt in my own mind; my sections speak too plainly for any doubt. My account also agrees exactly with the results recently made known by Mitsukuri[1] in Chelonia. If one compares my fig. 19 with his fig. 11, one will be easily convinced that a certain stretch of epithelium on each side of the median chorda-*anlage* becomes eventually incorporated in the mesoblast.

Let us now pass to the trunk and observe the mode of mesoblast formation in that region. Fig. 13 shows a transverse section from the dorsal region of an embryo in which no cephalic protuberance is seen as yet. In the median line the epiblast shows a thickened medullary plate (*n. p.*) formed of high columnar cells. Immediately beneath, but distinctly separate from, this plate, there is the chorda-hypoblast (*ch. h.*) forming the entire roof of the invaginated tube. Its

1. Further studies on the formation of the Germinal Layers in Chelonia: The Journal of the College of Science, Imp. Univ., Japan. Vol. V. p. 1.

constituent elements have acquired the tall columnar shape by repeated longitudinal division. The hypoblastic cells immediately outside the chorda-hypoblast have an elongated shape and are in active multiplication as shown by many karyokinetic figures seen in this part. The products of the divisions are accumulated as a triangular mass between the epiblast and the yolk. This is the *mesoblast* (*mes.*). It is clearly distinguished from the yolk mass not only by a distinct slit but also by the characters of its constituent elements which are smaller, have their nuclei stained deeper, and are less full of yolk granules than yolk-cells. Also karyokinetic figures are often visible in this mass, while they are of rare occurrence in the yolk-cells. Thus, the mesoblast arises here as paired masses budded out from a few hypoblast cells placed immediately outside the chorda-hypoblast. This account agrees substantially with that given by Calberla.[1] The mesoblast cells facing the epiblast acquire a columnar shape, arrange themselves more or less regularly, and become the parietal layer of the mesoblast. In fig. 13, this layer has been more or less formed and has become continuous with the external extremity of the chorda-hypoblast. The cells lying below the parietal layer are irregularly arranged and are still having new cells added from the hypoblast cells of the aforesaid part.

Figs. 14 and 15 are from the dorsal region of slightly older embryos. Fig. 14 is essentially like fig. 13. In fig. 15, which represents a section more posterior than fig. 14, the mesoblast mass of one side is isolated, while that of the other side is still continuous with the hypoblast. In fig. 16, the mesoblast masses of both sides are entirely cut off from the hypoblast and have assumed a triangular shape, of which the inner and outer sides are formed by the parietal, while the ventral side

1. E. Calberla:—Ueber die Entwicklung d. Medullarrohres u. d. chorda dorsalis d. Teleostier u. d. Petromyzonten. Morph. Jahrb. Bd. III.

is occupied by the visceral layer. There are a few cells lying between the two layers which ought perhaps to be looked upon as belonging to the visceral layer. The chorda-*anlage* is now distinct and separated from the adjacent hypoblast by peculiar spindle-shaped hypochordal cells which are probably derived from cells originally lying between the chorda-hypoblast and the origin of the mesoblast. In fig. 17 from a still older embryo, the formation of the chorda is now completed. The hypochordal cells surround it as before. The gut-hypoblast has slipped itself under the chorda and the hypochordal cells, and forms the definitive roof of the enteric cavity. Fig. 18 shows the stage in which the medullary cord, the chorda, the hypochordal cells and the mesoblast masses have been completely differentiated.

It need scarcely be pointed out that the process of the mesoblast formation in the trunk is an abbreviated form of that observed in the cephalo-cervical region. One form does not, of course, suddenly pass into the other, and in the anterior part of the trunk (at just about the place where the head-protuberance is joined to the more posterior globular part) we can see the phases of gradual transition.

Fig. 23 is from the more anterior part of this region. *X* is the fold that starts from the outer wall of the enteric cavity to push itself towards the median line. The gut-diverticulum is decidedly shallower than in fig. 20. Cells seem to be budding forth from the outer extremity of its wall. Figs. 24 and 25, from an older embryo, are sections taken more posteriorly. In fig. 24 the more anterior of the two, the mesoblast mass is being budded out from each side of the chorda-*anlage* but there is now no trace of the alimentary diverticulum. The hypochordal cells have slipped under the chorda. The cells of the definitive gut-hypoblast are still outside the strip where the mesoblast cells have been budded out. In fig. 25, they are pushing themselves below the chorda and hypochordal cells to form the permanent median

roof of the enteric cavity. My observations lead me to conclude that the process of the mesoblast formation begins in the region round the blastopore and proceeds forwards as the gastral mesoblast. This is contrary to the conclusion of Kupffer and of Shipley.

C. *The lateral and ventral portions of the mesoblast.* In the cephalo-cervical region which is free from yolk-cells, the lateral and ventral portions of the mesoblast are formed by the simple downward growth of the distal or outer extremity of the mesoblastic fold. In the region of the trunk, the process is somewhat modified on account of the presence of yolk-cells. The gastral mesoblast in this region does not extend itself laterally and ventrally as a solid sheet of cells. The distal border of the gastral mesoblast gives rise to free and separate cells, which penetrating between the yolk-cells and the epiblast establish in time a complete layer of a single row of cells.

This has been sufficiently demonstrated by Shipley (*loc. cit.*) At the same time, the peristomal mesoblast becomes free from the lips of the blastopore, and as separate scattered cells push their way between the epiblast and the yolk-cells and contribute to the formation of the mesoblast in the part ventral to the blastopore. This circumstance may be the reason why the previous investigators have overlooked the peristomal mesoblast. Thus, at about the stage given in fig. 18, the whole mesoblast has no connection with any part of the primary layers. The subsequent growth of the layer is solely effected by cell-multiplication within the layer itself. The posterior growth of the mesoblast is brought about not by any fresh addition from the hypoblast or any other structure but only by the extension of its own territory.

D. *The metameric segmentation of the mesoblast.* The metameric segmentation of the mesoblast begins first in the dorsal region and proceeds both backwards and forwards. When the segmentation has

been completed the first somite lies just behind the auditory vesicle (*auv.* fig. 26).

According to Scott, (*l. c.*, p. 160), the segmentation into metameres precedes in the Selachians the separation of the protovertebrae from the lateral plate, but both processes occur simultaneously in *Petromyzon*. I learn, however, from my sections that *Petromyzon* is exactly like the Selachians in this respect.

The formation of the germinal layers in *Petromyzon* as given above accords well with the general plan of the development of these layers in the Vertebrata, as shown in *Amphioxus* by Hatchek, in *Triton* and *Rana* by O. Hertwig, and in *Trionyx* and *Clemmys* by Mitsukuri. The points of agreement and disagreement with previous writers[1] on *Petromyzon* as Calberla, Scott, Shipley, and Kupffer have been incidentally touched upon, in the course of the present paper and need not again be entered into in detail. In the main, my results agree best with those of Calberla.

Zoölogical Laboratory, Science College, Dec. 1891.

1. I regret that I have not seen the work by Max Schultze.

Explanation of Figures.

Complete list of reference letters.

au. v.	auditory vesicle.
bp.	blastopore.
ch.	chorda.
ch. h.	chorda-hypoblast.
ep.	epiblast.
ent.	enteric cavity.
hb.	hind brain.
hch.	hypochordal cells.
hp.	hypoblast.
it.	invaginated tube.
lp.	lateral plate (of mesoblast).
mes.	mesoblast.
mes. f.	mesoblastic fold.
mes. p.	peristomal mesoblast.
mes. s.	mesoblastic somite.
n.	neural cord.
np.	neural or medullary plate.
p. p. c.	pleuro-peritoneal cavity.
p. mes.	parietal mesoblast.
v. mes.	visceral mesoblast.
s.	segmentation cavity.
sm.	somatic mesoblast.
yc.	yolk-cells.

Plate XIII.

Fig. 1. Vertical section through an egg of the morula-stage. BB × 2 *(Zeiss)*.

Fig. 2. Sagittal section through an egg of the oldest morula-stage. BB × 2.

Fig. 3. Transverse section through the dorsal region of an embryo in which the gastrulation is going on. BB × 2.

Fig. 4. Sagittal section of an egg after the completion of gastrulation. BB × 2.

Figs. 5 and 6. Sagittal sections of an embryo in which the peristomal mesoblast is first seen. BB × 2. Fig. 5, a section through the median line; fig. 6 a section through a plane slightly lateral to the median line.

Fig. 7. Median sagittal section through the hind end of an embryo far older than that of the last two figures. BB × 4.

Figs. 8-11. Series of selected transverse sections from an embryo of about the same stage as that of fig. 7. BB × 4. Fig. 11 has been cut through the line *a b*, fig. 10 through the line *c d*, fig. 9 through the line *e f*, and fig. 8 through the line *g h*, in the embryo shown in fig. 12.

Fig. 12. Diagram of a median sagittal section through an embryo of about the same age as that of fig. 5, to show the directions of sections represented in figs. 8-11.

Plate XIV.

Fig. 13. Transverse section through the dorsal region of an embryo a little older than that represented in fig. 7.

Figs. 14 and 15. Transverse sections from the dorsal regions of a little more advanced embryo; fig. 15 is more posterior than fig. 14.

Fig. 16. Transverse section from the dorsal region of a still more advanced embryo.

Fig. 17. Transverse section from the dorsal region of a still more advanced embryo.

Fig. 18. Transverse section from the dorsal region of a much further advanced embryo.

Fig. 19. Transverse section through the anterior part of an embryo in which the head-prominence is ready to protrude.

Figs. 20-22. Obliquely transverse sections through the cephalo-cervical region. BB × 4.

Fig. 20. Transverse section of an embryo of a little more advanced stage than that of fig. 19.

Fig. 21. Transverse section from a still older egg.

Fig. 22. Transverse section from a still further advanced embryo.

Figs. 23-26 represent obliquely transverse sections through the plane by which the cephalic protuberance starts up. BB × 4.

Fig. 23. Transverse section of a little older embryo than that of fig. 20.

Figs. 24 and 25. Transverse sections from a still older embryo, fig. 24 being a more anterior one than fig. 25.

Fig. 26. Frontal section through the cephalo-cervical region of a much further advanced embryo.

Fig. 27. Sagittal section through an embryo of an advanced stage.

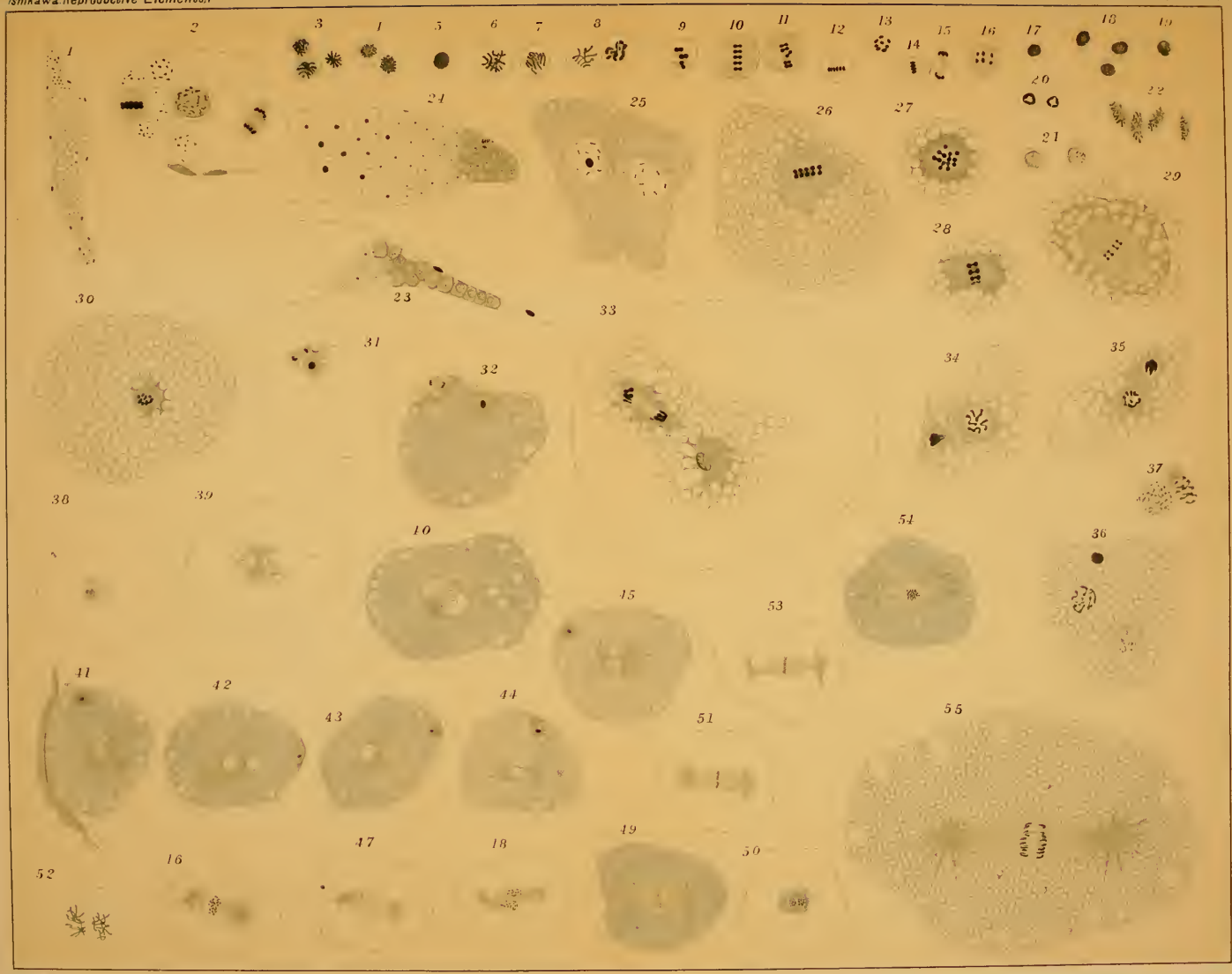
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Fig. 1

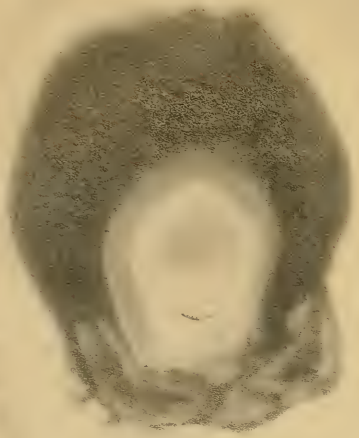
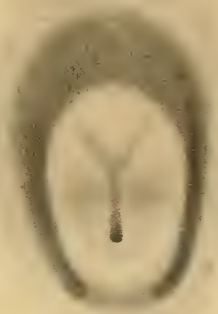


Fig. 4

Fig. 2



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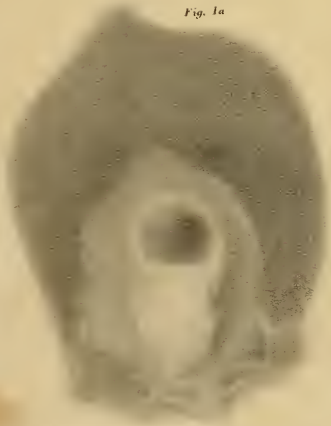

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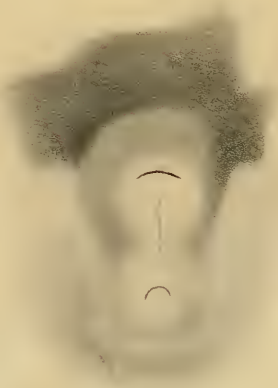

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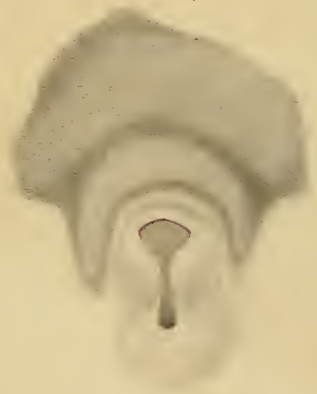

Fig. 4a

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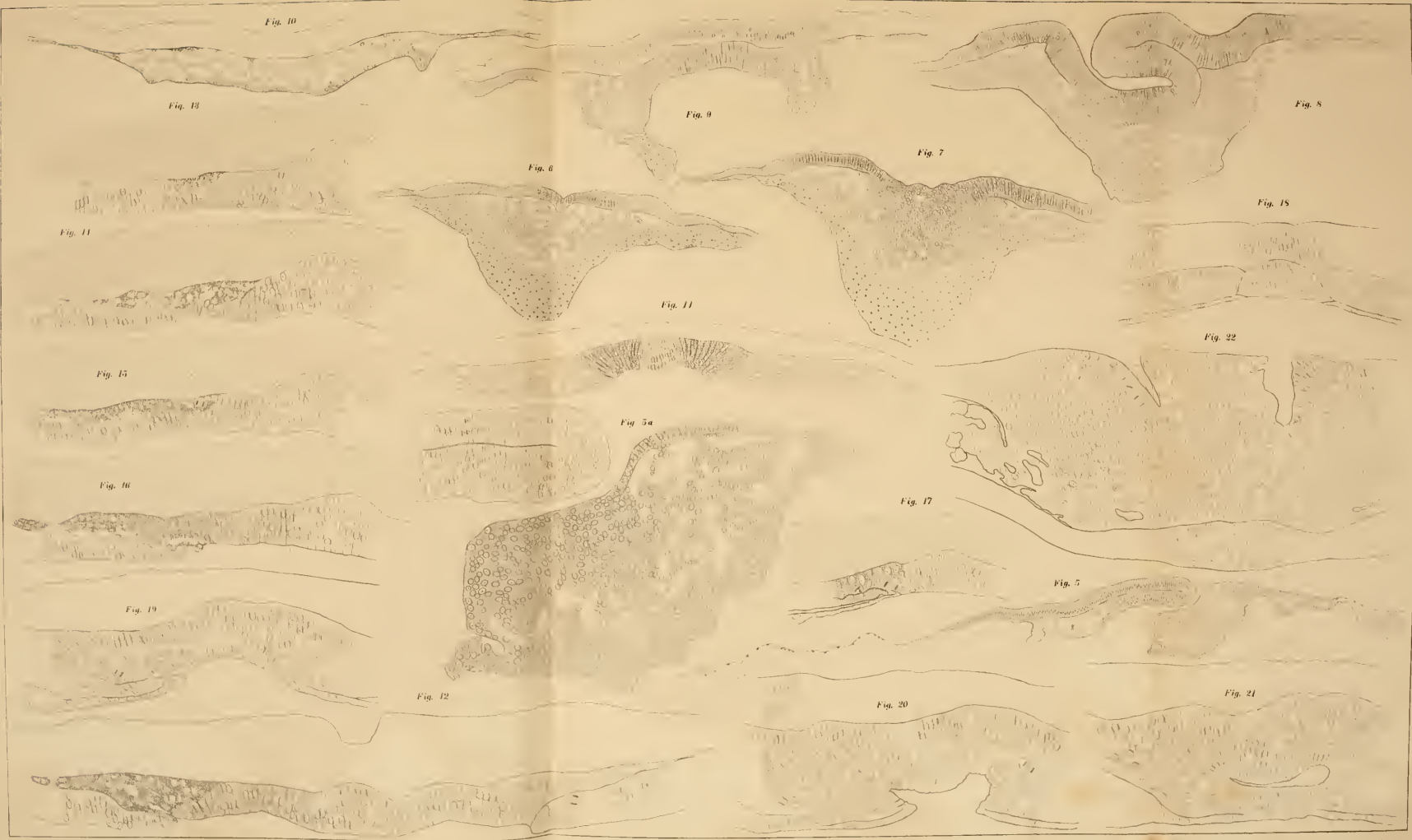
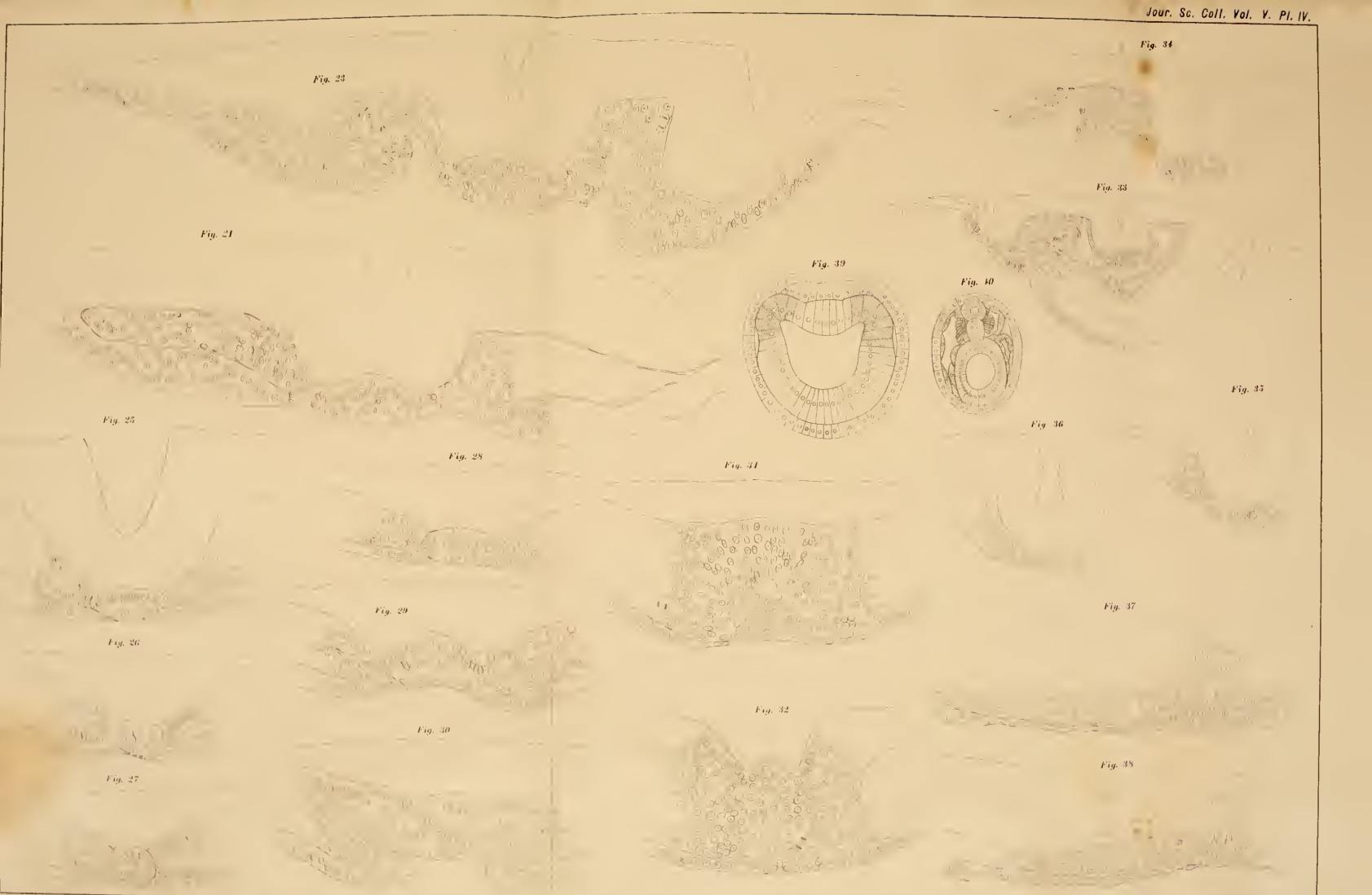
Lith. & Imp. The Seishi-bunsha



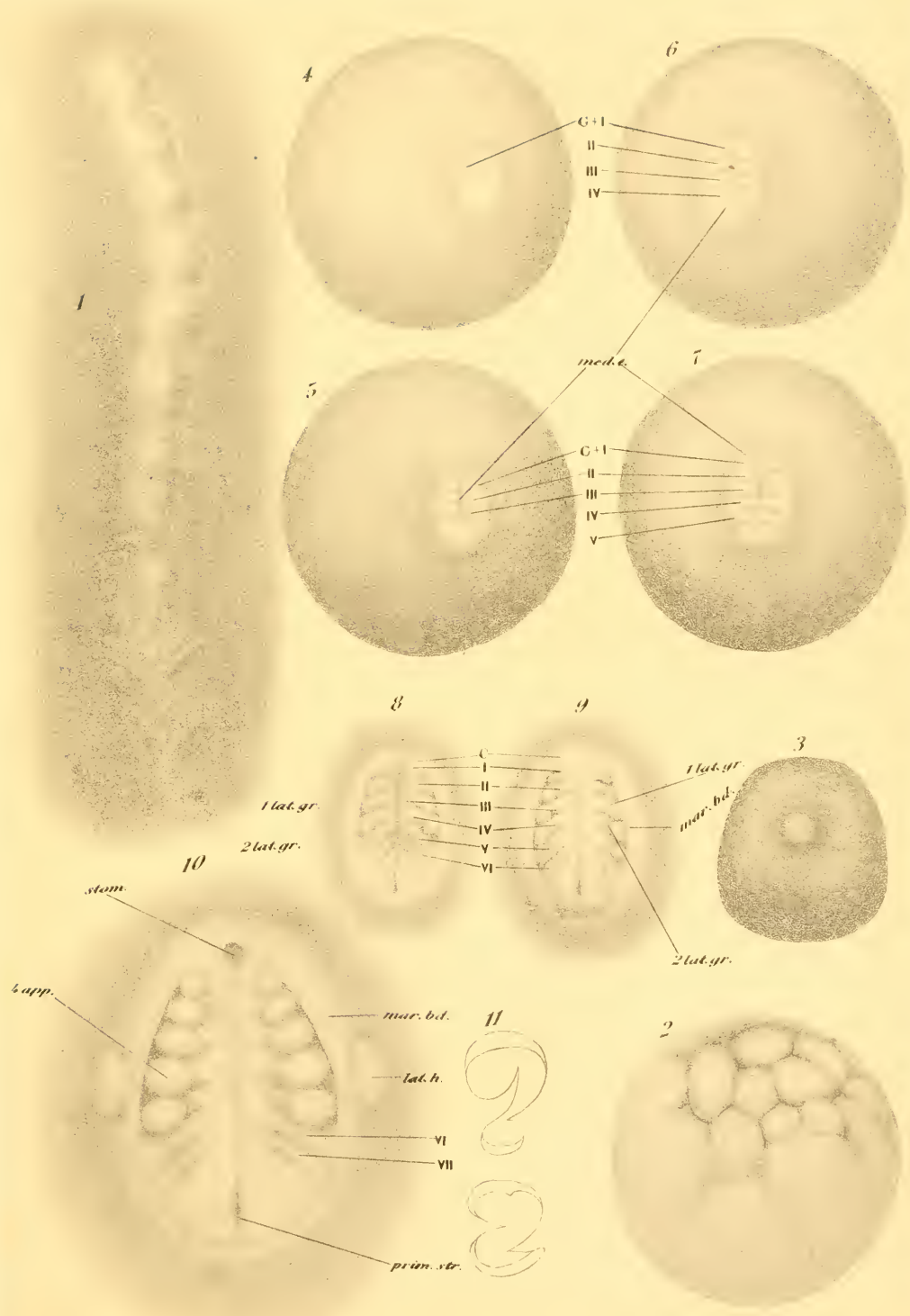
S. Mitsukuri & K. Nagahara del.

Lith. & Imp. The Seishi-Bunsha



K. Mitsukuri & K. Nagahara del.

Lith. & Imp. The Sanshi-hansha.



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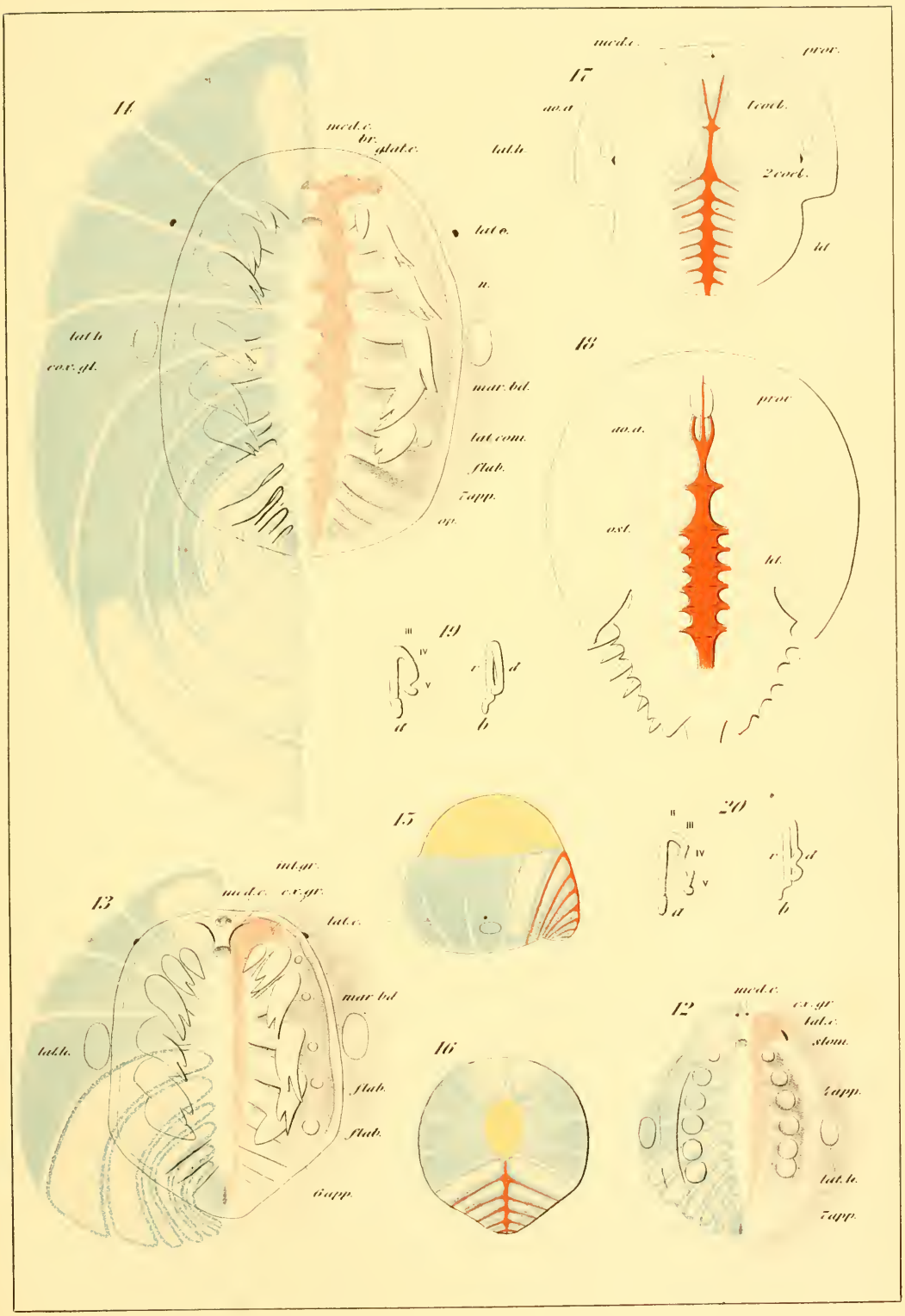

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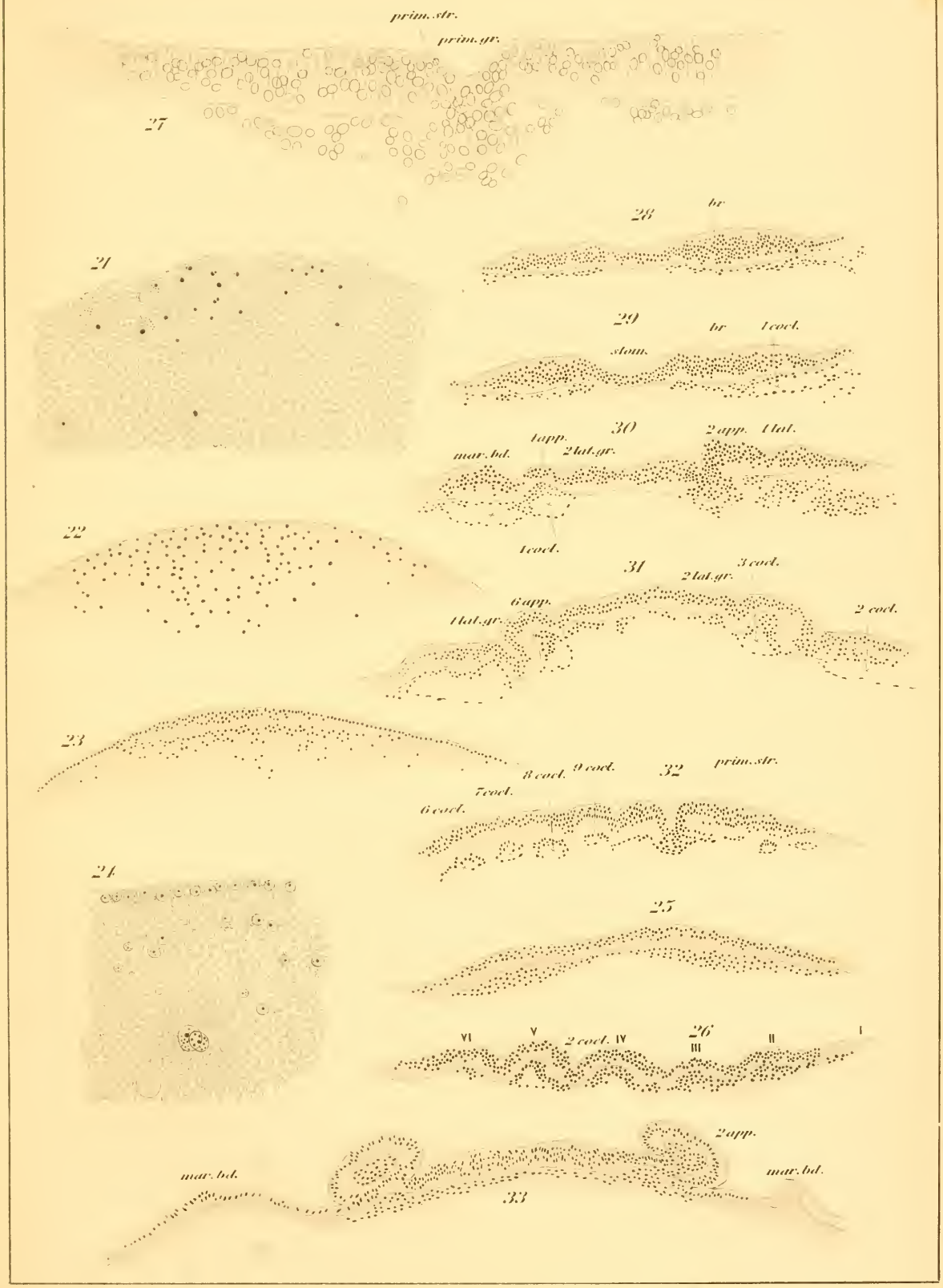

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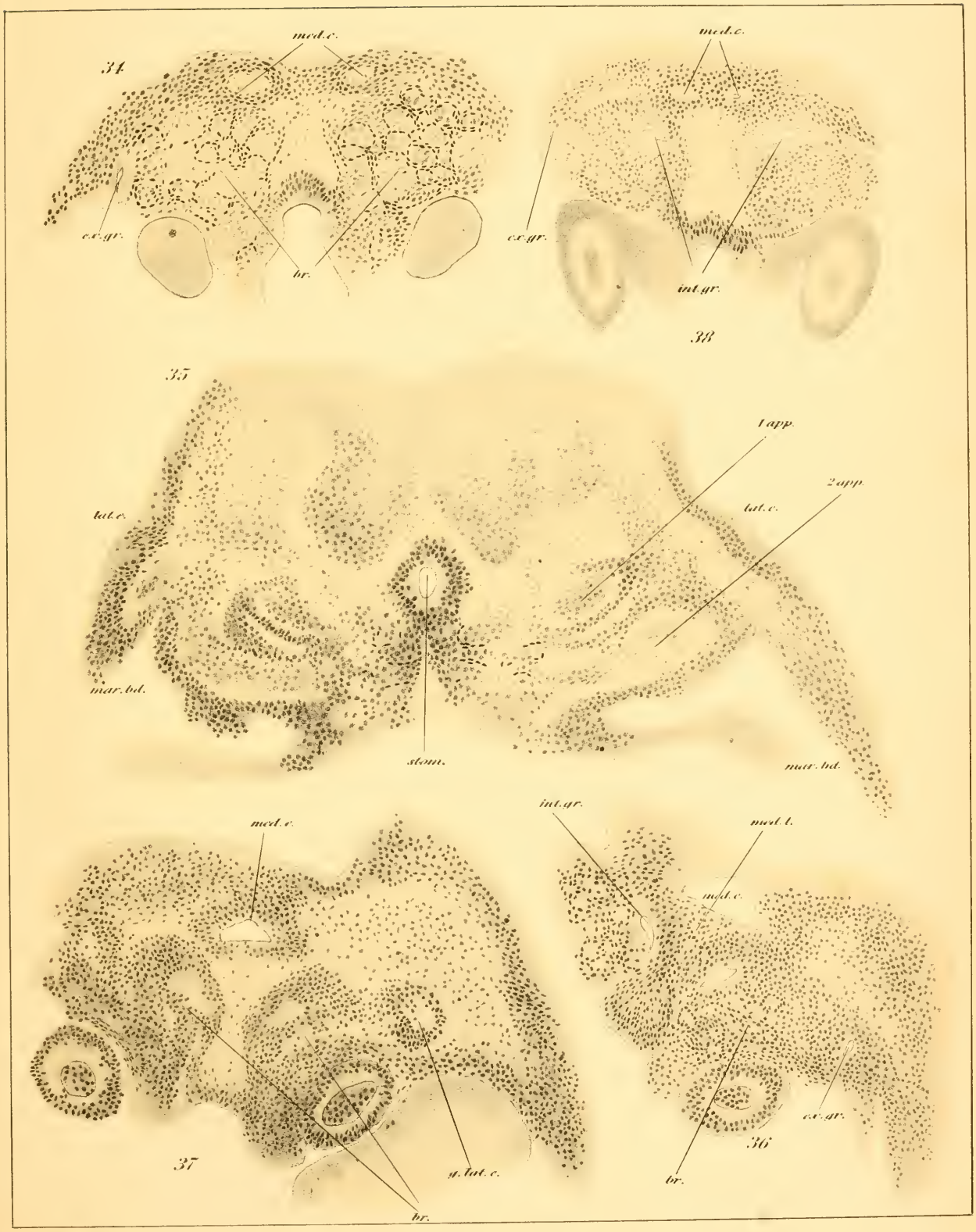

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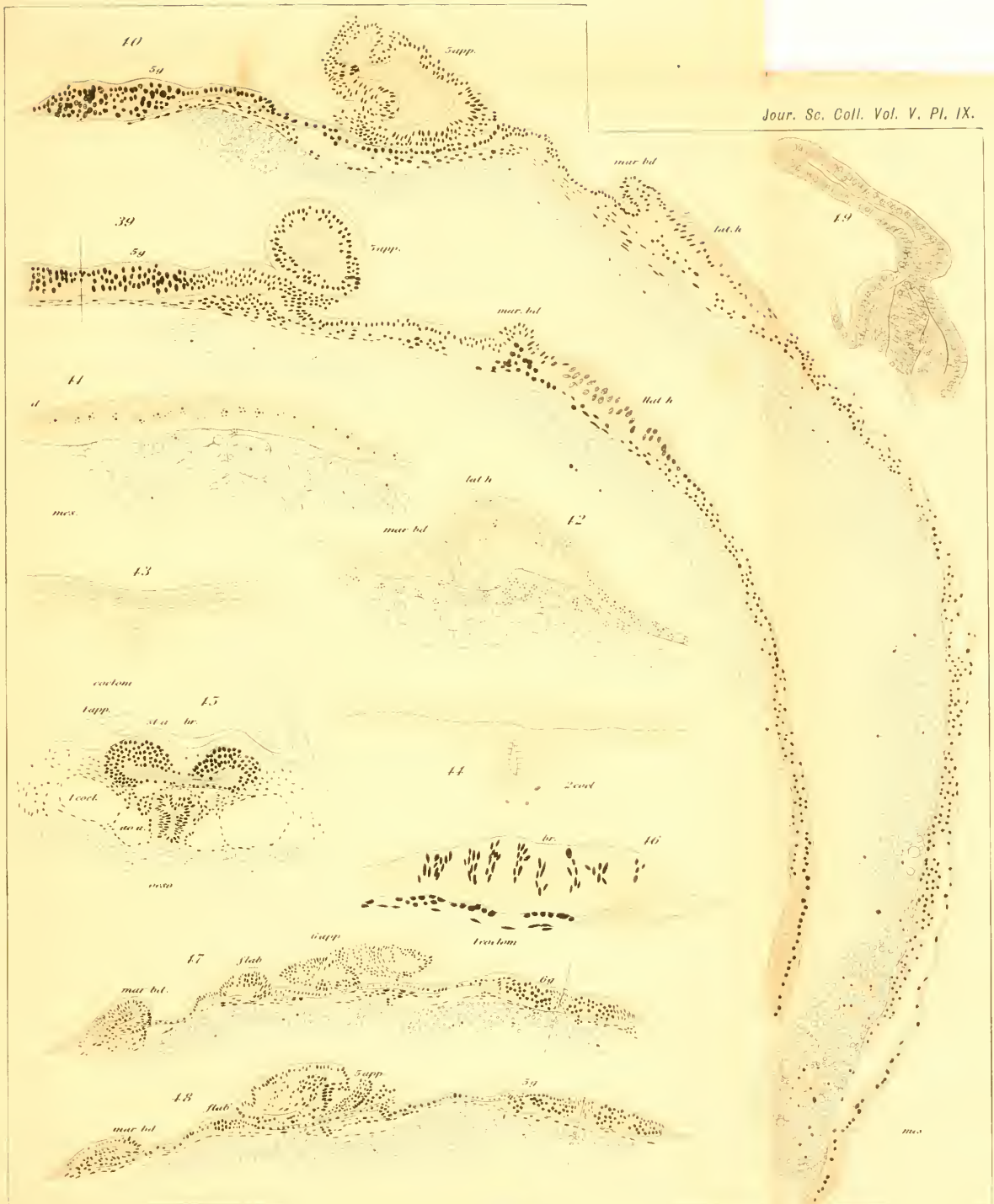

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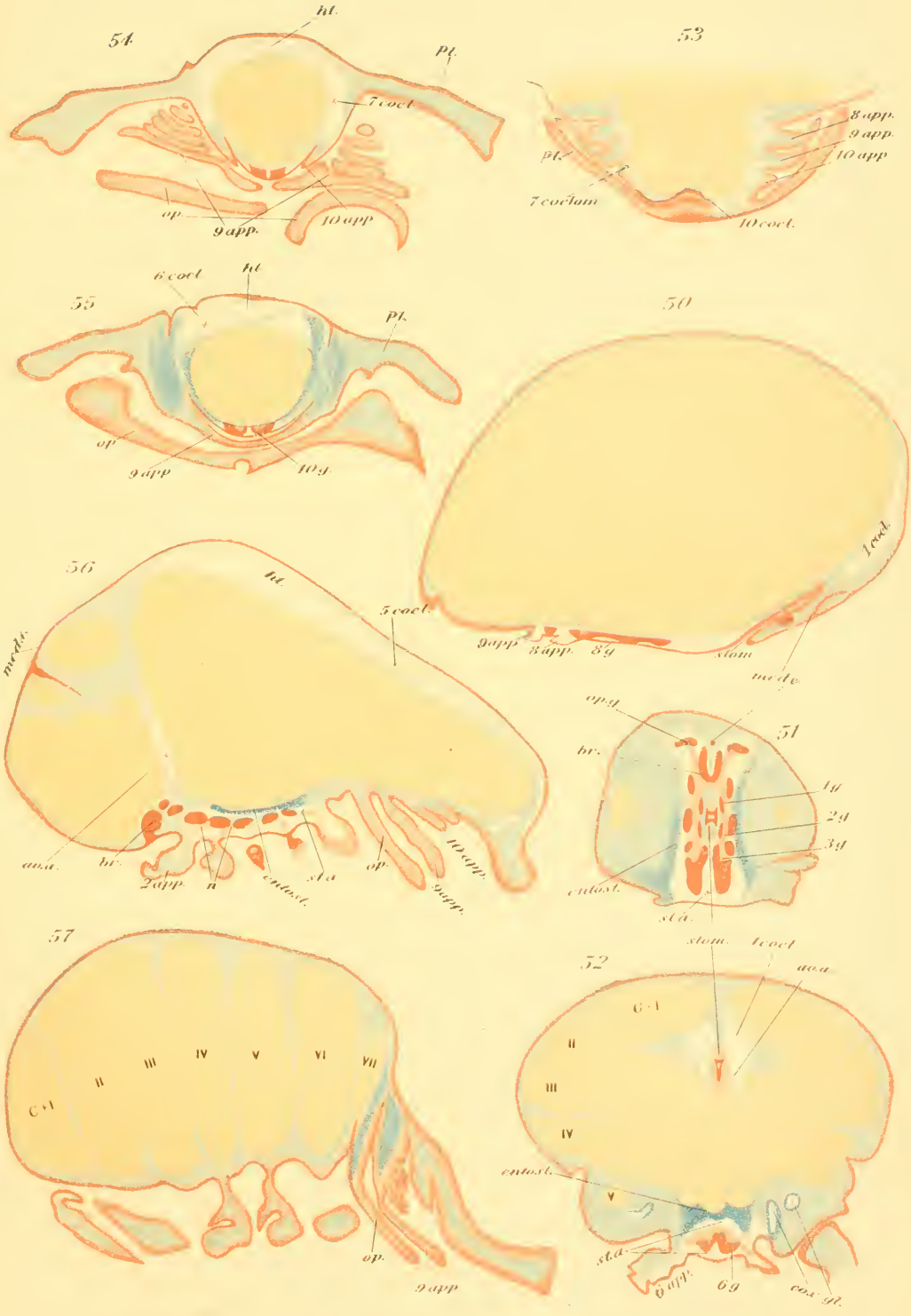

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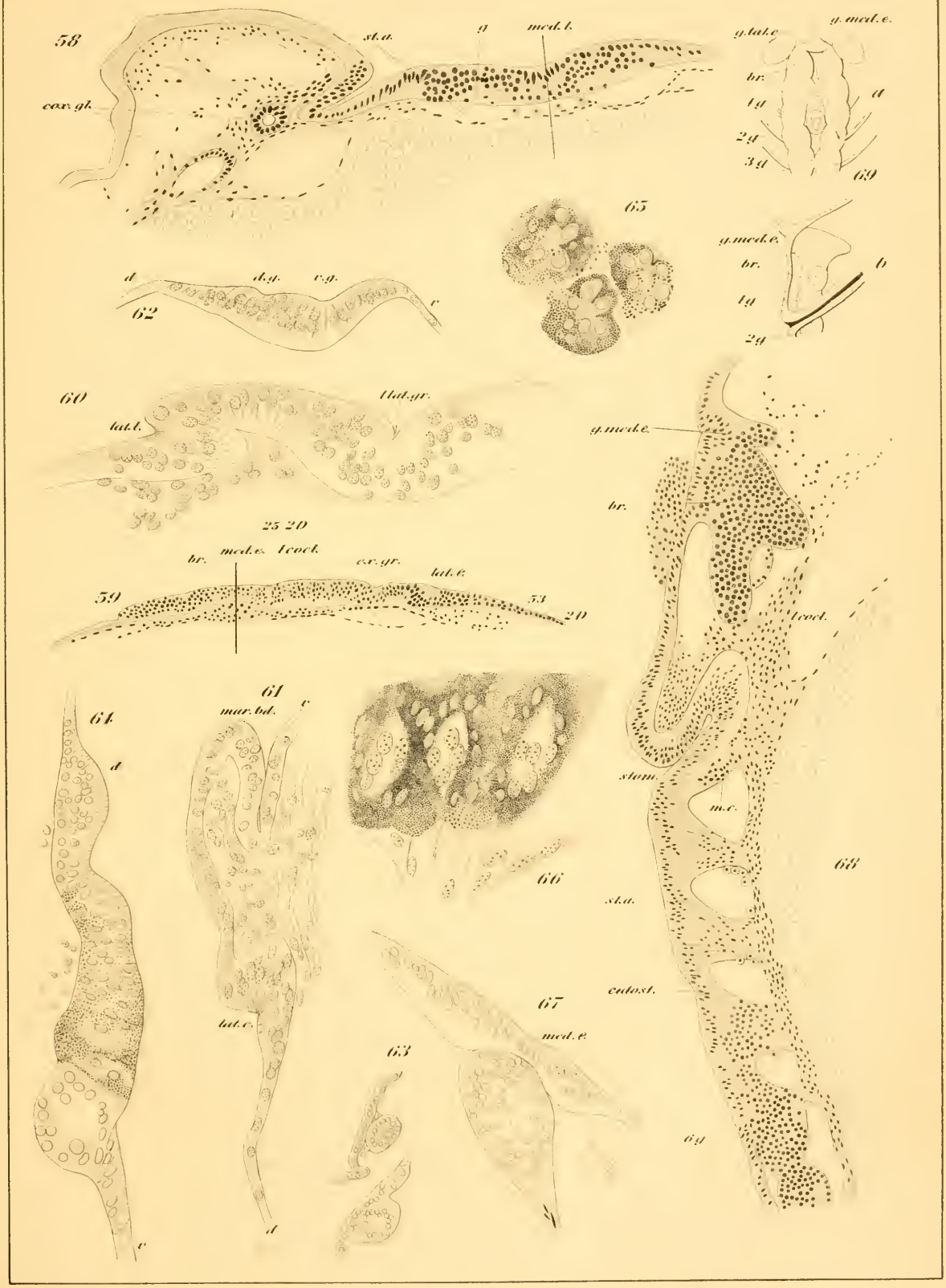

K. Kishinouye del.

THRIPONAX RICHARDSI.

(Male 1/3 Nat. size.)

Fig. 1

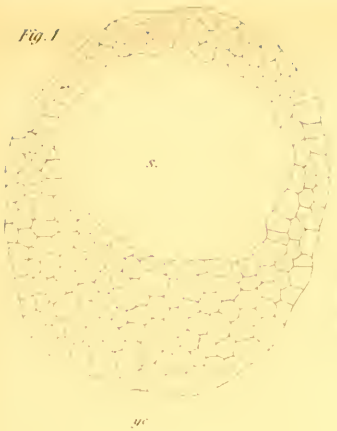

Fig. 2

Fig. 12

Fig. 3

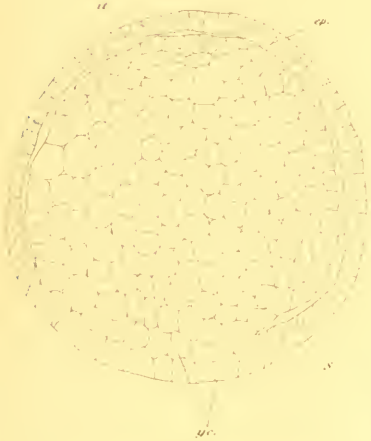

Fig. 5

Fig. 11

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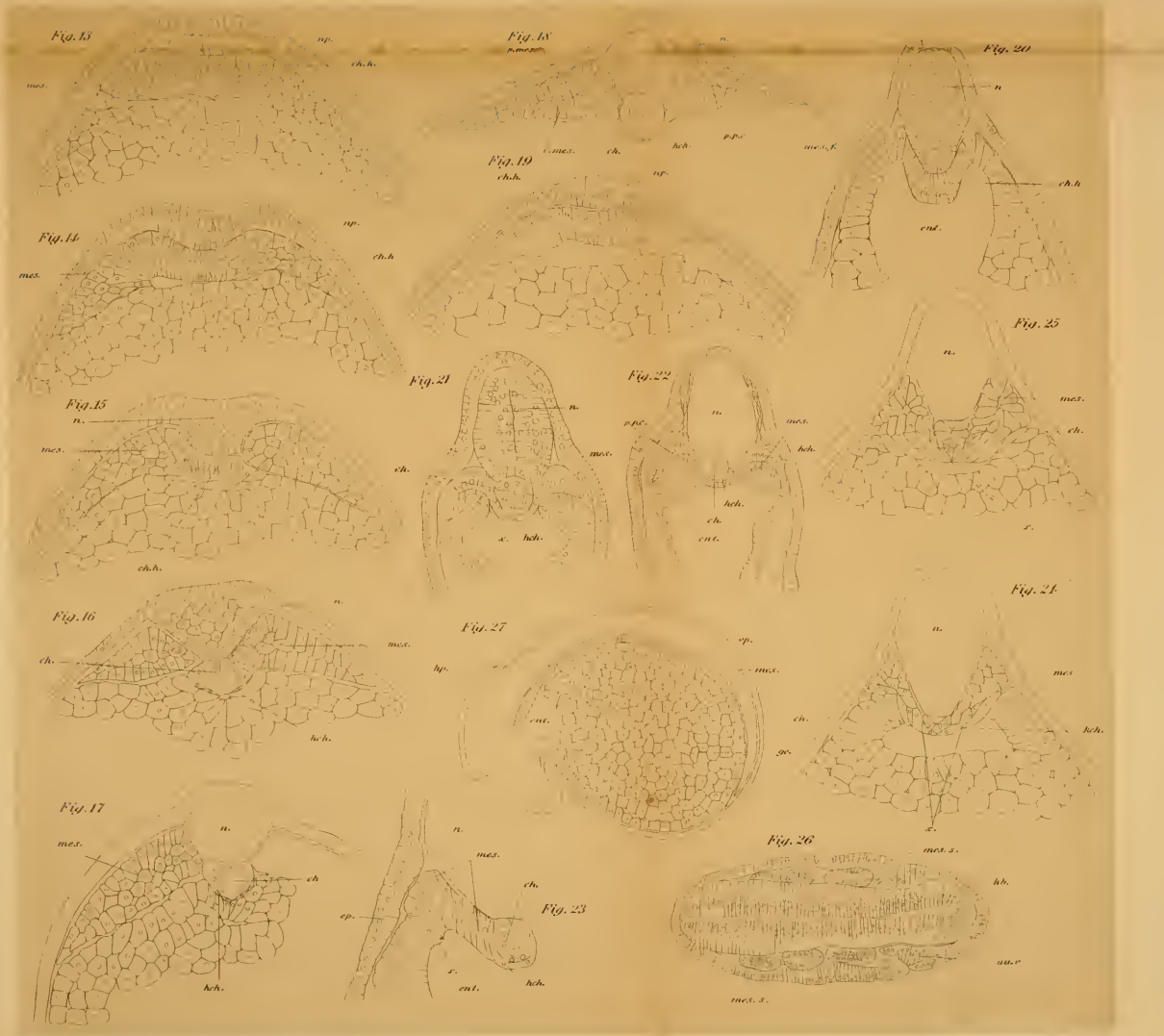
Fig. 13
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The Disturbance of Isomagnetics attending the Mino-Owari Earthquake of 1891.

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Plate XV-XXII.

Introduction.

One of the severest earthquakes in the record of this country devastated the districts about Gifu and Nagoya, on the 28th October 1891, of which a full account will shortly appear in this Journal. The Science College of the Imperial University, at the request of the writers, appointed a survey party, consisting of the writers and two advanced students of physics, Messrs. Ōta and Nakamura, for a new magnetic survey of the district affected. Frequent shocks of varying intensity occurred for a very long period after the date of the destructive one in October, and the party did not set out till some time after these shocks had sensibly ceased, namely, on the 20th December, returning on the 13th January.

The object in view in having this survey made, was to enable comparisons to be drawn between its results and those which had

been previously obtained, or which might be obtained, at some future time, in order to throw light if possible, upon the effect of seismic events upon the magnetic elements of a country, and give some notion concerning the nature of the subterranean disturbances to which such events are due. For the purpose of such comparison, it is evident that a knowledge of the ordinary secular variations of the magnetic elements of the district is of paramount importance, and this unfortunately, in the present case, is to a great extent wanting, since systematic magnetic surveys of this country are of comparatively very recent date.

If we take only the declination, we may go back to the work of Inō, who made a careful comparison of the compass needle with the astronomical meridian at various places in the country during his memorable undertaking of the geodetic survey of Japan, 1800—1818. Since then we have had observations of only a fragmentary nature until the first systematic survey was carried out by the Geological Bureau (1880—1885) under the direction of Dr. E. Naumann. Two observers, Messrs Sekino and Kōdari, worked during these years over different parts of the country, the number of stations being 182 in all. The results are published in a pamphlet entitled "Die Erscheinungen des Erdmagnetismus in ihrer Abhängigkeit vom Bau der Erdrinde." Their results were, however, of a provisional character, in so far that they made but one determination of each element at every station, and that the distribution of their stations was only along certain lines. This necessitated the introduction of corrections which, as there were no better means, they took from the Tōkyō magnetographs; while as to isomagnetics much extrapolation had to be made, notwithstanding the number of stations they took. This was no fault of the observers, for they had other duties to perform at the time, and the mode of travelling was not so convenient then as it is now.

During the summer of 1887, Prof. Knott and the present writers

with Mr. Imagawa made a survey, in which they tried to distribute the stations as uniformly as they could. They divided themselves into two parties, indicated as 'south' and 'north,' and as the principal work was done during the three months, July, August, and September, the errors due to the secular and seasonal variations were but small. The south party made observations of diurnal variations of declination at every station except three. This, besides giving the mean value of declination at the place, tells us the nature of the magnetic weather of the day on which other magnetic elements were determined. They made also three or four determinations of the horizontal intensity and dip, the times of observation being distributed over the day. (For details of this survey we refer to volume II of this Journal.) Had we made another series of such observations, we could have allowed for the secular variation in the results of the present survey, and should have been able to tell more definitely the kind of disturbance caused by the earthquake: but, as it is, our results will yet be of service for determining the secular variation, when, in the future, another survey shall be made, and then we may be able to draw inferences as to the effect of the earthquake by allowing for the secular variation then ascertained.

There was no particular division of work among the members of the party; generally speaking, however, the vibration and deflection experiments were carried out by the writers and either of the students; the dip was determined almost exclusively by the students; and the declination and time-observations, both for the chronometer rate and for azimuth, were undertaken by the writers.

The stations, as a simple matter of course, were those of the previous survey in 1887. Although for guidance we had verbal descriptions of the stations, and the memory of one of the party who had worked on the previous occasion, the identification of places was not always easy, as no fiducial mark of reference had been left. This was to be

expected, since in the previous survey we had tried to station ourselves in places which were as far as possible from buildings and hills. Warned now by this experience, we left a wooden post with the short inscription, "磁力實測點," and the date, at each place of observation, while further we give (Pl. XV) some topographical details of the localities, as was done by Lamont, hoping thereby to save much time and labour and to give much certainty in identifying the places in future.

The four stations, Nagahama, Obama, Shioya, and Isshiki (Kamiyashiro, in previous reports), are almost identical with the former spots, *i. e.*, are within a few metres. In Nagoya, the Normal School of the province has since been built on the site of the former station, and we were obliged to have our new station a little to the east, that is, in the back part of the recreation ground. Here we made observations of dip in four places in different quarters of our tent, to see if the new building, though of wood, had any disturbing effect, and as the results agreed within reasonable limits, we assumed that it had not caused any sensible magnetic disturbance. This way of taking the dip at several points in vicinity was carried out in nearly all stations where local disturbance was feared. In Shimizu, a coal depot had been built on the site of our previous station, and the present determination was made in a place about 100 metres to the north-west along the shore. Numazu and Hamamatsu are new additional stations.

We further took some of the soil from the station and measured its magnetic permeability. This was done by measuring the magnetic moment in known field. The field was given by a solenoid of 39.1 cm. length, uniformly wound with No. 13 copper wire, to 13.7 turns per cm. in 6 layers. In order to eliminate the solenoid effect, it was placed in vertical position, and the magnetometer stood 5.2 cm. west of the middle point of the solenoid; there the direction of the field

due to the ends of the solenoid is up and down, and consequently it gives no deflection so long as there is no substance in the solenoid. This position was determined experimentally by passing a strong current through the solenoid. The soil to be experimented upon was filled into a glass tube which had been tested and found to be sensibly free from magnetic matter. The inner diameter of this tube was 1.3 cm. and its length 19.55 cm. When introduced into the solenoid, its lower end was brought nearly level with the magnetometer, so that only the upper half of the solenoid was used. The magnetometer deflection was a maximum when the lower end of the glass tube was slightly below the level of the magnetometer, and in this position the reading was taken. Taking the deflection as proportional to the strength of the pole induced by the field, and applying the correction due to the upper pole, the susceptibility was easily deduced. The only soils that gave any sensible susceptibility were those of Numazu and Shimizu, two stations which are so far east of the region under consideration that they do not come into the chart of isomagnetics at the end of this paper. The results of the determinations are as follows :—

Soil from Numazu Station.			*Soil from Shimizu Station.*		
$\mathfrak{H}$	$\mathfrak{I}$	κ	$\mathfrak{H}$	$\mathfrak{I}$	κ
26.8	.0199	.00074	26.8	.0059	.00022
85.0	.0817	.00096	85.0	.0238	.00027
127.0	.1266	.00099	137.0	.0355	.00026

It is remarkable that these soils seem to be far from being saturated in these fields.

In the following description of stations we give the geological nature of the soils.*

* We are indebted to Mr. Y. Kikuchi, Assist. Prof. of Geology, for giving this information about the soils.

Numazu $\varphi = 35^\circ\ 6'$ $\lambda = 138^\circ\ 52'$

East bank of Kanōgawa, about 150 metres north of the bridge.

Soil :—Pyroxenes, olivine, plagioclase ; derived from basalt. Magnetite abundant.

Shimizu $\varphi = 35^\circ\ 0'.2$ $\lambda = 138^\circ\ 30'.3$

100 metres N of coal depot, 15 metres from the sea.

Soil :—Pyroxenes, quartz ; derived from volcanic rocks. Magnetite plentiful.

Hachimanmura $\varphi = 34^\circ\ 44'$ $\lambda = 137^\circ\ 45'$

About 200 metres N of Hachiman-Yashiro, in the farm.

Soil :—Quartz, pyroxenes, apatite, magnetite (very little), hornblende, tourmaline. Probably derived from crystalline rocks.

Nagoya $\varphi = 35^\circ\ 10'.7$, $\lambda = 136^\circ\ 55'$

In the east corner of the play ground of the normal school.

Soil :—Pyroxenes, quartz, felspar.

Nagahama $\varphi = 35^\circ\ 23'.8$, $\lambda = 136^\circ\ 16'.0$

Eastern shore of the lake, and former site of castle, edge of the mulberry farm.

Soil :—Quartz and hornstone pebbles.

Obama $\varphi = 35^\circ\ 30'.3$, $\lambda = 135^\circ\ 44'.8$

Former site of fortification, south bank of Kumagawa, 70 metres N W of Minatsuki Yashiro.

Soil :—Loam.

Shioya $\varphi = 36° 18'$, $\lambda = 136° 14'$

South shore of the Japan Sea, 150 metres N of the cremation building.

Soil :—Mostly quartz and felspar fragments.

Isshiki $\varphi = 34° 30'.4$, $\lambda = 136° 45'.3$

Middle of salt farm, former site of fort.

Soil :—Derived from slaty rocks.

Instruments and Method of Observation.

The object of the present survey being to get results closely comparable with those obtained in the previous one, we took the set of instruments that was used by the ' south ' party of 1887, for the sake of eliminating instrumental peculiarities should there be any ; since the regions to be visited had then been exclusively surveyed by that party. Of the instrumental constants we give new determinations somewhat in detail.

Declination Coil.—Its length is 13.3 cm.; breadth, 13.2 cm.; height, 2.7 cm.; the space unwound in the middle 2.4 cm.: thus nearly fulfilling the condition for minimizing the error due to excentric position of the magnetometer, in which the ratios of these dimensions are 5 : 5 : 1 : 1. The coil is wound in two layers, the under layer with somewhat fine wire to 22.2 turns per cm., and the upper one with thicker wire to 13.2 turns per cm., making in all 35.4 turns. The field at the centre is $6.5 \times 35.4 \div 10 = 23$ per ampère, or 0.013 ampère will give .3, the approximate value of H in

those regions, so that a Daniell element prepared in a small bottle proves sufficient to give the requisite field. Its internal resistance varies between 20 and 60 ohms., according to the strength of the solution in the Daniell cell. In order to adjust the strength of the current for use, a small resistance box consisting of 1, 2, 4, 8, 16, 32 ohms was put in the circuit. This arrangement of resistances gives the fewest number of plugs with which the resistance can be adjusted, within one ohm, from 1 up to the total sum of resistances in the box.

The method of observing the declination was the same as before described ; that is, by finding the two positions of the coil where its magnetic axis coincides with the direction of the earth's field, in one of which the pivots are reversed after the usual fashion of collimating telescopes. The mean of the two azimuths is taken to be the position of the Υ's of the theodolite in magnetic E.-W., corresponding to the instant at the middle of two observations ; and the difference as the magnetic collimation of the coil. This magnetic collimation should be constant if the instrument remains perfectly unaltered in shape. The collimation varied from $\frac{1}{2}'$ to $1'$ on different occasions. We first thought this difference to be personal, but after some number of trials, it was found that the same collimation was obtained by different observers when they worked in close succession, and that the change was gradual and in the instrument. It might be supposed that this fluctuation in the collimation is due to variation of the declination during the course of observation. But the process of observation takes only two or three minutes, in no case more than five minutes, and since the greatest change of declination is only about two minutes per hour, this change cannot be the cause. The fluctuation is due probably to temperature variation of the coil.

The position of the circle corresponding to the astronomical meridian was observed, together with the time; and was calculated,

by the usual method, from simultaneous equations containing time, azimuth, and collimation.* For this sort of work the usual method of forming normal equations by differentiation is altogether superfluous, and we follow the abridged method of Cauchy. By this means we found two azimuths from two sets of observations on successive nights, when weather permitted ; on other occasions, observations were made, one in the evening, and one early next morning. The results of the two determinations usually came out within 10″; this difference is due to two sources, one the error of observation, and the other the error of graduation. The latter will be eliminated to a great extent by taking a number of observations on some circumpolar stars, and a number of readings of the azimuth circle on different parts of the graduation. For this purpose, we have published in *Sugaku-butsuri-gakkwai-kiji.*, vol. V., a somewhat extensive table of azimuths of *Polaris*, for different hour angles and latitudes, which can be used for observations of either α or λ *Ursæ Minoris* for several years to come. As these two stars differ by nearly 6 hours in right ascension, it will always be possible to take observations which differ by several minutes of arc in azimuth in course of half an hour.

Magnet.—The magnet is a solid steel bar of nearly square cross section polished on all sides. Its magnetic moment was found to have fallen a great deal, and we therefore remagnetized it a few days before starting, taking care not to reverse the previous magnetization. Placing the magnet on a glass plane, it was found to be distinctly curved. A lateral face of this magnet, which has better polish than the others, has a round spot towards the north end, and this face with the mark always served as the reflecting face in our vibration experiments. It has remained nearly plane, while the faces perpen-

* See reduction sheet at the end.

dicular to it had become slightly curved. This change of shape necessarily altered the moment of inertia of the magnet.

The dimension of the magnet was therefore redetermined. The magnet was laid on a thick plane glass plate, and placed in contact with the graduated side of the standard metre scale. This scale is of brass, constructed by Breithaupt (Hesse Cassel), and equal to one metre, at 20° C. The two extreme edges of the magnet were slightly convex, and were not distinct enough to serve as marks for measuring the length of the magnet. Two similar, right-angled, glass prisms were made to touch the faces of the magnet, perpendicular to its length. The edge of the prism was well defined, and was brought in the same plane with that of the metre scale. The readings of the edges of the prism were taken by means of a micrometer microscope. The magnet was placed on the glass plate on all its four faces successively, and the same series of observations repeated for each position of the magnet. The magnet was then taken off and the distance between the edges measured under the microscope. This done, the magnet was reversed and its length measured again in the same way as before.

To correct for change of length by temperature, two thermometers were placed beside the magnet, and two laid on the scale. All these thermometers were previously compared with the standard thermometer. Temperature readings were taken simultaneously with those of the micrometer. Generally, the temperature of the magnet did not differ by more than 0°.1 from that of the scale.

The following table gives the results of observations by Messrs. Ōta and Nakamura.

Observed Length of Magnet. cm.	Position.	Temp. of Scale.	Temp. of Mag.	Length at 0°C	Observer.
7.0053	direct.	16°.7	16°.7	7.0010	S.N.
6.9994	reversed.	16°.8	16°.9	6.9977	„
6.9973	direct.	16°.3	16°.3	6.9956	K.O.
6.9990	reversed.	16°.6	16°.6	6.9973	„

In the reduction of scale to 0°. C. the expansion coefficient of brass was assumed to be 0.0000189, and that of steel, 0.0000106. From the mean of these observations, the length of the magnet is 6.9979 cm. The length has thus somewhat diminished since the former determination, by which it was found to be 7.0024 cm.

The breadth of the magnet was measured at three points; *i.e.*, at the ends and at the middle. The magnet was placed perpendicular to the metre scale and between the two prisms before mentioned. The same process of measurement as used for the length, gave 0.8066 cm. at 0°C. for the mean breadth of the bar or its thickness between the face with the mark, and the one parallel to it. The breadth of the other faces is of minor importance, and has not been measured.

In weighing the magnet a Sartorius' balance was used. Care was taken not to place the magnet near any of the iron used in various parts of the balance, by not putting it on the scale pan, but suspending it from this by a slender thread, bringing it about 50 cm. below the balance case and about the same distance above the floor. The magnet was shielded from air currents by placing it in a nearly closed glass vessel. The mass of the magnet, as determined by a set of weights from Sartorius, was 35.0561 grm., and 35.0633 grm. by the set of weights formerly used. This discrepancy was cleared up by comparing these weights with those made of quartz by the

same maker, belonging to the Chemical Laboratory of the College. The brass weights from Sartorius were a little heavier, and the old weights a little lighter. The following gives the results of the experiments :—

	by Sartorius weights.	by old weights.
Observed	35.0561 grm.	35.0633 grm.
Correction	+ .0038	− .0034
Mass	35.0599 grm.	35.0599 grm.

The mass of the magnet is thus 35.0599 grm.

From these measurements of length, breadth, and mass the moment of inertia of the magnet about an axis through its centre of inertia, and perpendicular to its length, is found to be 144.98 at 0°C.

The moment of inertia was calculated on the supposition that the magnet is a parallelopiped having the dimensions given above. The magnet, however, being distinctly curved, it was not satisfactory to use the moment of inertia calculated in the above manner, and it was therefore determined also experimentally.

This was done in the usual way by comparing the times of vibration, with and without an additional inertia. In order to eliminate the diurnal variation of H, the vibrations were repeated several times in which the inertia rod was alternately on and off. The inertia rod was a solid cylinder of brass belonging to a Kew magnetometer (64) (length = 9.545 cm., diameter = 0.997 cm., mass = 63.071 grm.) From the comparison of the times of vibration in these two cases, the moment of inertia was found to be 144.995. The following table gives the results of observations by Mr. Ōta :—

Observed time of vibration.

Magnet alone.	Temp.	Magnet with inertia red.	Temp.
2ˢ.7276	19°.1		
		5ˢ.6783	17°.1
2 .7244	16°.2		
		5 .6736	15°.0
2 .7231	14°.6		
		5 .6743	15°.0
2 .7238	14°.7		
Deflection for complete rotation of torsion head.	11′.1	Deflection for complete rotation of torsion head.	13′.8

The temperature coefficient for the moment of the magnet was taken from calculations made on the observations at Isshiki.

Temperature Coefficient of Magnetic Moment:—In the former survey, no correction for the difference of temperature in vibration and deflection experiments was applied in the reduction of the observations of horizontal intensity. This gives the moment of the magnet at mean temperature; but the value of the horizontal intensity is affected inasmuch as the magnetic moment was different in the two experiments; it will have been less if the temperature was higher in the vibration than in the deflection experiment, and *vice versâ*.

The determination of the temperature coefficient of a magnet is a matter of some difficulty. It is desirable to determine the effect of temperature on the magnetic moment by placing the magnet in the same state as in the determination of horizontal intensity. By taking the number of observations of horizontal intensity at different hours of the day, so that there is sufficient difference of temperature during the experiments, we can obtain data for the calculation of the temperature coefficient. With this object in view, many observations of the horizontal intensity were made at Nagoya.

The magnet, however, showed a sudden decrease of moment at Nagahama. It is likely that the temperature coefficient after this fall of moment was different from that at Nagoya. By using the moments found at Isshiki, the temperature coefficient was recalculated. For reducing the results of the former survey, the temperature correction was calculated from determinations of magnetic moment made at Miyazaki.

The following empirical formula was used in the calculation,

$$M = M_0 + m + a\,(t - t_0) + b\,(t - t_0)^2$$

where M_0 is the mean of the moments used, m a small correction to be applied to M_0, t_0 the mean temperature, and a, b the coefficients to be determined. The above formula was then transformed, for convenience of calculation, to

$$M_t = M_\tau \{1 + \alpha(t-\tau) + \beta(t-\tau)^2\}$$

where τ is any convenient temperature. The following gives the data and results of calculation from observations made at Nagoya, Isshiki, and Miyazaki :—

Nagoya.

Magnetic Moment.	Temperature.	
670.86	16°.23	
671.03	16 .12	$M_0 = 673.49$
671.93	14 .84	$m = -\ 0.02$
673.32	11 .13	$t_0 = 11°.48$
675.06	8 .00	$a = -\ 0.546$
675.90	7 .53	$b = +\ 0.0046$
676.44	6 .49	

whence $M = 674.31\{1 - .00083(t - 10°) + .0000068(t - 10°)^2\}$

Isshiki.

Magnetic Moment.	Temperature.	
656.90	11°.28	
657.55	9 .03	
657.95	8 .38	$M_0 = 658.19$
657.81	8 .14	$m = -\ 0.05$
660.79	2 .07	$t_0 = 7°.83$
658.17	8 .55	$a = -\ 0.418$
656.61	11 .25	$b = 0.0057$
659.77	3 .93	

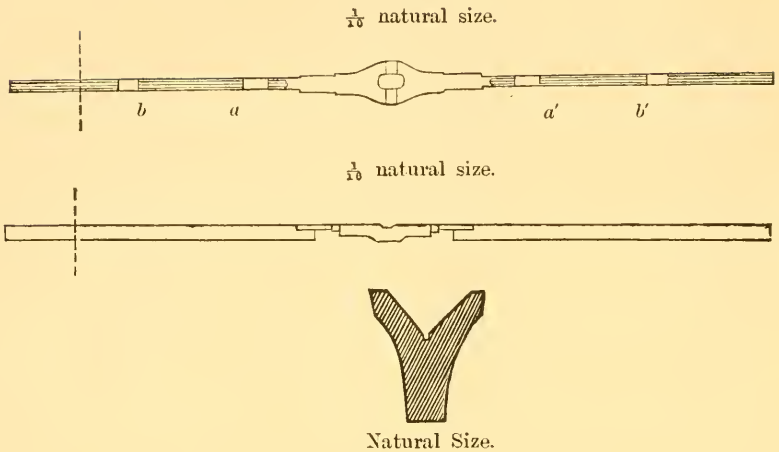
whence $M = 657.26\{1 - .00060(t - 10°) + .0000087(t - 10°)^2\}$

Miyazaki.

Magnetic Moment.	Temperature.	
436.945	34.6	
437.01	34.8	$M_0 = 437.45$
437.07	34.0	$m = -\ 0.04$
437.19	33.35	$t_0 = 32°.33$
437.58	31.6	$a = -0.221$
437.95	29.6	$b = 0.0076$
438.44	28.35	

whence $M = 437.96\{1 - .000586(t - 30°) + .0000174(t - 30°)^2\}$

Deflection Rod :—The rod is of brass and about 1 metre long. The accompanying figures show the rod in horizontal and vertical projections, as well as in cross section. **V** grooves are cut all along the slender parts $a\ b$, $a'\ b'$ of the rod. When the magnet is laid on **V**, the diagonal of the square cross section of the magnet is on a level with the upper face of the rod. To facilitate the change of position of



Natural Size.

the deflecting magnet and to restore it always to the same place, four stops a, b, a', b' are rigidly fixed to the rod. These stops are triangular prisms of brass fitting into the V. Each has a slightly oblique section. It is so fixed to the rod that the magnet comes in contact with the acute edge of the prism along the diagonal of the square section. Before placing the magnet on the V, the groove was always carefully swept with a camel's hair brush, so as to make sure of contact, both along the groove, and against the stop. The magnet was placed in such a position that the lateral face with the spot before spoken of was always turned from the observer. The magnet was slid by the end of the brush along the groove. In transferring it from one to the other side of the rod, or in reversing it, care was taken to guard against change of temperature from handling, by wrapping it in a piece of folded crape.

The temperature of the rod was read by means of two thermometers (Salleron No. 1386 and No. 15476), each graduated to $\frac{1}{5}$ of a degree. They were loosely attached, one to each branch of the rod. One of the thermometers was placed in front of the observer, and the

other at the back. These thermometers were compared with the standard and corrected.

During the former survey, the magnet remained straight and came into good contact with the stops and therefore the distances, r_1 and r_2, of the magnet from the magnetometer magnet were known from the measurements of the distances a a', b b', and the length of the magnet. But as the magnet had become decidedly curved, it would no longer come into good contact with the stops. Generally, only one extremity of the diagonal of the square cross-section was in contact, while there was a slight gap at the other end. This change of contact necessitated the redetermination of the distances of the centre of the magnet in positions a, b, a', b'. The actual distances of the centre of the magnet from the magnetometer magnet can only be determined by placing the magnet in the groove in the same way as in the actual deflection experiments.

The deflection rod was placed on a plane plank, and the lower side of the metre scale was brought in contact with the upper face of the rod. To guard against any change of position of the metre scale and the rod, the latter was gently clamped to the plank at its middle, and any relative motion which might take place between the two during measurement was noted by a microscope of high magnifying power. No relative motion of the scale and rod was observed during the operation. The magnet being placed in the usual way in the groove, the edge of the magnet adjacent to the stop was sighted, and the, readings of the scale and micrometer noted in the four positions a, b. a', b'. The magnet was then reversed, and the process repeated. The rod being next reversed, the readings of the other edge of the magnet were noted in the same position as before. For each reading of the micrometer, four thermometers were read, two being placed on the scale and the others close to the rod. The mean of the observed

lengths are.—

$$a\,a' = 39.0759 \text{ cm.} \quad \text{at } 0^\circ \text{ c.}$$
$$b\,b' = 67.0196 \text{ cm.} \quad \text{,, ,, ,,}$$

The distance between the edges of the magnet was next measured, both in the direct and in the reversed positions. The mean length of the magnet from one edge to the other was found equal to 6.9905 cm. at 0° C. Thus we have for the distances of the centre of the magnet from the magnetometer magnet.—

$$r_1 = 30.0196 \text{ cm.} \quad \text{at } 0^\circ \text{ C.}$$
$$r_2 = 23.0332 \quad \text{,,} \quad \text{,, ,, ,,}$$

It is to be noticed that the distances of the magnet from the magnetometer magnet will be slightly different unless the latter be accurately centred. Since the centering of the magnetometer magnet can be easily done with sufficient accuracy, and since the correction te be made from this cause would be only of the order of the square of this error, it was quite negligible in our observations.

The distances of the magnet for two positions, a and b, had to be corrected for the expansion of the rod as well as for that of the magnet. If the expansion coefficient of brass be α, and that of steel be β, it can be easily shown that in place of the factor $(1+3\alpha t)$ (see specimen sheet in the former report), used in the calculation of M/H in the former survey, we must use.—

$$1+3\alpha\left(1+\frac{\alpha-\beta}{\alpha}\,\frac{l}{r_1+r_2}\right)t$$

where l denote the half length of the magnets.

Taking $\alpha = 0.0000189$, $\beta = 0.0000106$, $l = 7/2$, $r_1 = 30$, $r_2 = 23$, the value of the coefficient becomes—

$$1+3.08\,\alpha t\,;$$

or its effect is to increase the temperature coefficient by about 3 per cent.

Correction for the induced Magnetism:—The magnetic moment arising from the magnetization induced in the vibration magnet by a given magnetic field, comparable with that of the earth, was determined by the magnetometric method. The magnet was placed on the deflection bar, as in the actual deflection experiment, and was subjected to various weak fields obtained by means of a solenoid enclosing the magnet and the bar together. The deflection due to the permanent magnetism of the magnet was compensated by means of another bar magnet placed on the other side of the magnetometer on the deflection bar. A solenoid, 23 cm. in length and 2.6 cm. in diameter, was wound in four layers with fine insulated copper wire, the total number of turns being 71 per cm. The effect of the solenoid alone was calculated by observing the deflections when the known current was passed through the solenoid, the magnet being taken away. This deducted from the deflection when the magnet was put in, gave the deflection proportional to the moment induced by the field. For observing the deflection, a scale cut in mm., was placed at a distance of 4.2 metres from the magnetometer. By means of a telescope, the deflection could be read to the tenth of a scale division. At each observation of deflection, the magnetometer zero was noticed, to guard against any changes of declination. The following are the results obtained by Messrs. Ota and Nakamura:—

Field.	Increment of moment.	μ (Increase of M per unit field)
.157 (direct)	.101	6.43
.306 ,,	.201	6.56
.157 (reverse)	.102	6.50
.306 ,,	.199	6.51
	Mean.	6.50

This result is greater than the value used in reducing the observations of 1887. The induction coefficient then used was 3.6, and was deduced from the observations made in 1883 on the magnet from which the present magnet was prepared by cutting off its end.

We tested the result by the ballistic galvanometer method. For this purpose a coil, into which the magnet fitted almost exactly, was wound, and its ends were led to a low resistance ballistic galvanometer which was 10 metres distant from the coil. The coil lay on a horizontal plane with its axis parallel to the magnetic meridian, and it was adjusted to this position by means of a wooden block. When the coil was quickly turned round through half a revolution in the horizontal plane the ballistic galvanometer gave deflections proportional to the number of lines of force through the solenoid due to the horizontal component of the earth's field. Now the bar magnet was put into the solenoid, and the experiment repeated; the magnet was introduced again with its axis reversed, so as to eliminate its direct effect on the galvanometer. The following is the result of this experiment :—

Mean of 10 readings of galvanometer throw without magnet 9.1
„ „ „ „ „ „ with magnet 125.7
Volume of magnet ... ... 4.5 c. cm.

The ratio of the volume included by the solenoid to that of the magnet is 1.44; whence $\mu = \frac{116.6}{9.1} \times \frac{4.5}{4\pi} \times 1.44 = 6.62$, which is greater than the value obtained by the other method. The difference is such as might be expected from the difference in the methods, as the first partly depends upon the distribution of induced magnetism in the magnet, and the second on the integral effect of induction on the substance. In applying the correction due to induced magnetism in the reduction of our observations, we have taken the value obtained by the first experiment, as it refers more directly to the point in question.

As we suspected that the change in the value of μ might be due to the change in the tempering of the magnet, caused probably by the annual variations of temperature during the years intervening, we made experiments on a similar magnet newly made, before applying this correction to the previous results. The bar was tempered as hard as we could make it, and the experiment was performed both in the unmagnetized and in the magnetized state. In both cases the value came out in slight excess of the values of the old magnet, contrary to the above supposition; we therefore apply the correction to our previous results. The values of H for 1887 recalculated by applying all the necessary corrections are found in the appendix.

Dip.—This was also the instrument that was used in 1887, *i.e.*, No. 88 Dover. Needle No. 2 was always used.

Results of the Survey.

The individual determinations of the magnetic elements are given in full in the table appended to this paper. We here compare the mean values with those of the previous survey.

DIP

Station.	1887	1891-2	Difference.
Numazu	——	48° 29′.0	—
Hamamatsu	——	48° 20′.2	—
Nagoya	48° 58′.2	48° 53′.8	−4′.4
Nagahama	49° 17′.6	49° 13′.6	−4′.0
Obama	49° 30′.4	49° 23′.5	−6′.9
Shioya	50° 30′.8	50° 25′.1	−5′.7
Isshiki	48° 16′.8	48° 16′.7	−0′.1
Shimizu	48° 41′.3	48° 37′.1	−4′.2

DECLINATION

Station.	1887	1891-2	Difference.
Numazu	——	4° 19′.45	—
Hamamatsu	——	4° 18′.92	—
Nagoya	4° 31′.9	4° 38′.56	+6′.66
Nagahama	4° 45′.1	4° 42′.81	−2′.29
Obama	4° 54′.1	4° 49′.30	−4′.80
Shioya	4° 59′.2	4° 56′.15	−3′.05
Isshiki	4° 21′.8	4° 23′.91	+2′.11
Shimizu	4° 2′.1	4° 4′.42	+2′.31

HORIZONTAL INTENSITY

Numazu	——	.30102	——
Hamamatsu	——	.30141	——
Nagoya	.29903	.30125	+.00222
Nagahama	.30039	.30086	+.00047
Obama	.30020	.30195	+.00175
Shioya	.29551	.29668	+.00117
Isshiki	.30210	.30288	+.00078
Shimizu	.30016	.30070	+.00054

TOTAL INTENSITY

Numazu	——	.45414	——
Hamamatsu	——	.45342	——
Nagoya	.45553	.45823	+.00270
Nagahama	.46058	.46069	+.00011
Obama	.46230	.46391	+.00161
Shioya	.46471	.46562	+.00091
Isshiki	.45395	.45511	+.00116
Shimizu	.45467	.45487	+.00020

The mean values of these elements are the arithmetical mean of all the observed values, except those for the declination, which are obtained in a different way. The curves given in Pl. XVI and XVII were traced upon tracing cloth, cut out and weighed. From the ratio of their weights to that of a rectangular piece of the same cloth covering 24 hours the mean value was easily deduced. This procedure we found more practical than that with Amsler's planimeter.

Through the kindness of Mr. K. Nakamura of the Central Meteorological Observatory, the photographic records of the magnetic elements at Tōkyō during the present survey were placed at our disposal. The inspection of these records showed us that the magnetic weather during the survey was generally fair, except on three days on which we were taking observations at Obama, Shioya, and Isshiki. The disturbances do not appear to be very serious, and as our curves of declination obtained in those places are not far from being regular, we take the mean value without applying any correction.

During the course of the survey, we felt two earthquakes, one at Nagoya and the other at Shioya. The former was not very severe but was accompanied by the usual rumbling, the latter though not accompanied by sound was a much stronger one. Both of them happened while we were observing declination, and we took observations of declination immediately the shock was over. Pl. XVI shows that the declination suffered a distinct fall at Nagoya but resumed its regular course after an interval of some minutes. In Shioya the fall was not so marked as in the case of Nagoya, especially as the shock happened in that part of the day in which the declination was rapidly falling. Whether this is due to change in the direction of the earth's field, or to distortion of azimuth on the part of the instrument, or in the ground on which it stood, we can not tell. In the case of the

Nagoya observations certainly, it is more than can be ascribed to the displacement of the instrument, as the azimuth determined on the two successive nights, one before and the other after the event, agreed within 6″: on both nights the transits of 7 stars were taken, the reduction sheet of which we here append.

Nagoya: December 24.3 Chronometer mean solar, No. 1594 Negus.

Observer, A. Tanakadate

Star.	δ	α	Z. D.	Clamp.	T(obs.)	Rate.	Diur. Aber.	Bb.	α-T(corr)	A.	C.
		h m s			h m s	s	s	s	h m s		
α Pers.	49°29′	3 16 36.76	14°18′ N	W	10 14 21.01	−3.79	−0.03	+1.15	6 57 41.61	−0.378	+1.539
ε Eridani	−9°50	3 27 50.73	44°59′ S	W	10 25 31.40	−1.98	−0.02	+0.55	39.22	+0.718	+1.017
ν Pers.	42°14′	3 37 51.56	7° 4′ N	W	10 35 29.32	−0.34	−0.02	+1.03	38.49	−0.165	+1.351
ζ Pers.	31°34′	3 47 20.65	3°36′ S	E	10 44 58.76	+1.18	−0.02	−0.05	39.10	+0.073	−1.173
ξ Pers.	35°29	3 51 57.53	0°19′ N	E	10 49 34.86	+1.72	−0.02	−0.05	38.98	−0.007	−1.228
ν Tauri	5°41	3 57 24.86	29°29′ S	E	10 55 2.04	+2.82	−0.02	−0.04	39.94	+0.495	−1.003
Gr. (2320) *s.p.*	111°55	4 5 58.63	76°42′ S	E	11 3 32.40	+1.21	+0.01	+0.02	38.04	+2.310	+2.374

Observations reduced to $3^h\ 40^m$. local sidereal time.

Whence

$$-\ 1.379\,c + 7.110\,a = +\ 5^s.69$$

$$+\ 12.969\,c - 1.186\,a = -\ 3^s.93.$$

$$a = +\ 0^s.76 = +\ 11''.3\,;$$

$$c = -\ 0^s.23$$

Azimuth reading 61° 7′ 50″

+ 11″

Meridian reading 61° 7′ 61″

Nagoya : December 25.2 Chronometer mean solar, No. 1594 Negus.

Observer, A. Tanakadate

Star.	δ	α	Z. D.	Clamp.	T(obs.)	Rate.	Diur. Aber.	Bb.	α-T(corrd.)	A	C
		h m s			h m s	s	s	s	h m s		
α Peg.	14°38′	22 59 21.10	26°33′ S	W	5 53 53.61	−4.15	−0.02	−0.27	5 54 27.74	+0.363	+1.033
τ Peg.	23° 9′	23 15 16.11	12° 1′ S	W	6 9 46.01	−1.57	−0.02	−0.30	28.01	+0.224	+1.080
ι Cassiop.	61°42′	23 20 0.42	26°31′ N	W	6 14 29.88	−0.81	−0.04	−0.53	28.08	−0.941	+2.109
λ Draco. *s.p.* ..	69°55′	23 25 0.09	74°52′ N	E	6 19 26.63	0.00	+0.05	+0.42	27.07	+2.811	+2.913
ι Andro.....	42°40′	23 32 18.91	7°30′ N	E	6 27 15.90	+1.20	−0.02	−0.73	27.56	−0.177	−1.360
ω^2 Aquil.....	−15° 9′	23 37 6.20	50°18′ S	E	6 31 32.72	+1.90	−0.02	−0.30	28.01	+0.797	−1.030
44 H. Ceph.....	67°13′	23 42 42.69	32° 3′ N	E	6 37 11.00	+2.87	−0.01	−1.18	30.02	−1.370	−2.581

Observations reduced to $23^h\ 25^m$. local sidereal time

Whence

$$+ 4.741\, c + 6.459\, a = 2.^s81$$

$$+ 9.199\, c + 0.396\, a = 1.^s78$$

$$a = + 0.^s30 = 4.''5\,; \qquad \text{Azimuth reading } 61°\ 7'\ 50''$$

$$c = + 0.^s18 \qquad + \ 5''$$

Meridian reading 61° 7′ 55″

A glance at the list of mean values will show that there is a change in all the elements, which are of different magnitude in different stations. In order to make this change more intelligible we have drawn isomagnetic charts of the region, both from the previous and the present results. Although we by no means pretend that the number of stations was sufficient to exhibit the actual magnetic condition of the district with detail, yet we believe that these lines are not far from represent-

ing the general course of isomagnetics about those regions. And this was all that we could do during the three weeks of winter vacation which we had to spare.

From the mean values at the stations, the intermediate values were interpolated graphically, by assuming the proportionality of the space variation of the elements between two stations, taking care to interpolate *across* the isomagnetics as much as possible. For the horizontal intensity and declination, as well as for the total intensity of the previous survey, the values obtained at Nagoya were so much out of the way that we at once perceived a local disturbance. We therefore excluded Nagoya in the first interpolation, as it would be wrong to assume proportionality across the space between which there is a maximum or minimum. When the isomagnetics are drawn with this exclusion, the course of the curves throws much light upon the nature of the local disturbance, which we indicate, according to our conjecture, by dotted lines.

We notice from these charts, that the general nature of the change is to make the lines more uniform than they were before. This is remarkably shown by the observations made in Nagoya where the local disturbance is very much reduced. Of all the systems of isomagnetics, the change for the equal horizontal intensity is the most striking. By the old survey these lines were considerably deflected from their general course, forming a kind of *ridge* along the Mino–Owari plane up to the north coast of Japan. By the new survey they are made more uniform, still converging towards the Wakasa Sea, beyond which the above named ridge might be carried.

Another remarkable point is that there was a minimum of total intensity about Nagoya, which now, by the new survey, causes only a small bend in the line of equal total intensity that passes very near the

place. With regard to the lines of equal dip the change is least marked. The bending of these lines towards the south are principally caused by the value of dip at Isshiki. In passing, we may remark that Isshiki lies very near the now well-known tectonic ridge along which the geological aspect of the country is suddenly changed. Another observation at a station somewhere between Tsu and Yokkaichi might tell whether this bend exists in the region generally, or whether it is of a more local character and peculiar to the southern coast.

As was stated in the introduction, we can not ascribe these changes solely to the effect of the earthquake, without thorough knowledge of the secular variation. But the very appearance of these charts is enough to show that they are anything but usual. The most important and interesting question that naturally arises will be—Are these changes of the magnetic state caused suddenly by the earthquake, or have they been taking place wholly or partly before it? The only results that we can refer to for information about the secular variation, are those of Messrs. Sekino and Kōdari. Mr. Sekino made 13 observations in various places in the close neighbourhood of Nagoya. About Nagahama and Obama there are no observations until we come to the region near Fukui, where Mr. Kōdari made 7 observations. The values of H as obtained by these observers are such as to change the course of the lines of equal horizontal intensity in those regions both in the chart for 1887 and in that given by Dr. Naumann in his paper: thus in the district near Nagoya H is .29, while in places near Fukui, which are 2 or 3 degrees north, the values of H are nearly .300, sometimes .304. It is difficult to conceive how Dr. Naumann obtained his lines of equal horizontal intensity as given in his chart, unless he excluded either of these sets of observations.

If we take Mr. Sekino's results in the neighbourhood of Nagoya as consistent among themselves, the course of the lines of equal horizontal intensity is very different from either of the two systems we obtained, as shown by dots in Pl. XIX. Considering that the course of these curves will be independent of the instrumental constants, we feel sure of the fact that these lines have been undergoing considerable variation during recent years about the Nagoya district.

The fact that the horizontal intensity has suffered the most disturbance, seems to show that the seat of that disturbance, if it exist at all, does not lie at great depth; and this is further confirmed by the smallness of the disturbances of all the other elements. Examining the chart that was provisionally prepared for the report of the previous survey, which is more detailed than the one published, we find the same kind of disturbance near Hamada—namely convergence of the lines of equal horizontal intensity towards the place; and we now recollect that it was here that the earthquake, which was the severest one preceding the present, was felt in 1872. Whether this disturbance is due to the change of magnetic condition of the earth's crust in the vicinity caused by strain, or to the change in conductivity for earth currents, or, again, is the result of the dislocation of the magnetic crust, is more than we can decide from the scanty data which we now possess. These points will undoubtedly afford most interesting subjects of research in the future.

Declination.

Station.	Declination.	Date and Hour. (L. M. T.)
Numazu	4° 21′ 26″	December 21 2h 34.8m p.m.
	4° 21′ 3″	„ „ 3 35.9 „
	4° 20′ 41″	„ „ 3 52.1 „
	4° 21′ 3″	„ „ 6 0.2 „
	4° 18′ 43″	„ „ 7 41.5 „
	4° 19′ 41″	„ „ 9 18.0 „
	4° 19′ 31″	„ 22 7 2.0 a.m.
	4° 18′ 46″	„ „ 9 12.6 „
Hachimanmura ... ... near Hamamatsu	4° 19′ 52″	„ 22 4 53.2 p.m.
	4° 15′ 54″	„ „ 8 51.3 „
	4° 17′ 39″	„ „ 10 13.0 „
	4° 18′ 37″	„ 23 7 55.0 a.m.
	4° 18′ 9″	„ „ 10 34.1 „
	4° 18′ 19″	„ „ 10 40.0 „
	4° 19′ 29″	„ „ 11 35.9 „
	4° 19′ 30″	„ „ 0 3.6 p.m.
	4° 20′ 44″	„ „ 1 18.1 „
	4° 20′ 51″	„ „ 2 36.4 „
	4° 18′ 49″	„ „ 4 14.2 „
	4° 17′ 54″	„ „ 6 55.5 „
	4° 17′ 34″	„ „ 7 10.9 „
	4° 17′ 44″	„ „ 7 37.7 „
	4° 18′ 22″	„ „ 9 1.4 „
	4° 18′ 21″	„ „ 9 56.8 „
	4° 19′ 4″	„ „ 11 15.9 „
	4° 18′ 57″	„ 24 0 27.2 a.m.
	4° 18′ 22″	„ „ 6 36.8 „
	4° 18′ 26″	„ „ 7 34.1 „
	4° 16′ 58″	„ „ 9 11.9 „
	4° 16′ 57″	„ „ 10 2.3 „
Nagoya	4° 39′ 20″	„ 24 7 44.3 p.m.

Station.	Declination.	Date and Hour. (L. M. T.)
Nagoya	4° 38′ 50″	December 25 0h 4.8m a.m.
	4° 37′ 42″	,, ,, 7 28.6 ,,
	4° 36′ 35″	,, ,, 8 28.3 ,,
	4° 36′ 47″	,, ,, 9 49.7 ,,
	4° 37′ 23″	,, ,, 10 58.6 ,,
	4° 39′ 48″	,, ,, 0 2.9 p.m.
	4° 40′ 44″	,, ,, 0 54.1 ,,
	4° 40′ 18″	,, ,, 1 9.7 ,,*
	4° 40′ 37″	,, ,, 1 47.7 ,,
	4° 40′ 18″	,, ,, 2 35.7 ,,
	4° 40′ 2″	,, ,, 2 49.1 ,,
	4° 38′ 59″	,, ,, 3 45.9 ,,
	4° 37′ 58″	,, ,, 4 31.0 ,,
	4° 38′ 4″	,, ,, 5 52.5 ,,
	4° 39′ 20″	,, ,, 7 9.9 ,,
	4° 38′ 53″	,, ,, 8 34.3 ,,
	4° 38′ 52″	,, ,, 9 10.8 ,,
	4° 38′ 25″	,, ,, 10 37.3 ,,
	4° 36′ 42″	,, 26 7 43.6 a.m.
	4° 34′ 48″	,, ,, 9 4.5 ,,
	4° 34′ 50″	,, ,, 9 59.7 ,,
	4° 35′ 25″	,, ,, 10 6.7 ,,
Nagahama	4° 33′ 48″	,, 27 11 45.6 a.m.
	4° 43′ 53″	,, ,, 0 43.3 p.m.
	4° 43′ 35″	,, ,, 1 59.7 ,,
	4° 42′ 50″	,, ,, 3 16.8 ,,
	4° 43′ 23″	,, ,, 3 48.3 ,,
	4° 42′ 23″	,, ,, 4 51.3 ,,
	4° 42′ 5″	,, ,, 6 35.4 ,,
	4° 41′ 33″	,, ,, 7 35.3 ,,

* Earthquake at 0h 59.1m p. m.

Station.	Declination.	Date and Hour. (L. M. T.)
Nagahama	4° 40′ 50″	December 28 8h 27m.8 a.m.
	4° 40′ 24″	„ „ 9 35.8 „
	4° 42′ 10″	„ „ 10 52.0 „
	4° 43′ 23″	„ „ 11 49.5 „
	4° 44′ 15″	„ „ 0 15.5 p.m.
	4° 45′ 8″	„ „ 1 9.4 „
	4° 44′ 15″	„ „ 2 6.3 „
	4° 44′ 0″	„ „ 4 15.3 „
	4° 43′ 3″	„ „ 5 14.5 „
	4° 42′ 50″	„ „ 7 3.4 „
	4° 42′ 35″	„ „ 8 31.3 „
	4° 42′ 48″	„ „ 8 47.9 „
	4° 43′ 5″	„ „ 8 52.2 „
	4° 42′ 50″	„ „ 10 39.4 „
	4° 42′ 23″	„ 29 1 1.6 a.m.
	4° 42′ 38″	„ „ 5 22.6 „
	4° 40′ 58″	„ „ 8 14.5 „
Obama	4° 49′ 38″	„ 30 0 54.4 a.m.
	4° 47′ 54″	„ „ 9 24.7 „
	4° 48′ 39″	„ „ 10 4.0 „
	4° 50′ 42″	„ „ 11 43.0 „
	4° 50′ 5″	„ „ 0 20.9 p.m.
	4° 50′ 5″	„ „ 0 33.4 „
	4° 49′ 15″	„ „ 1 57.9 „
	4° 48′ 43″	„ „ 2 21.1 „
	4° 48′ 43″	„ „ 4 20.6 „
	4° 49′ 13″	„ „ 5 26.2 „
	4° 48′ 53″	„ „ 10 43.4 „
	4° 50′ 43″	„ 31 5 22.3 a.m.
	4° 51′ 23″	„ „ 8 36.1 „
Shioya	4° 56′ 2″	(1892) January 3 4 24.3 p.m.

Station.	Declination.	Date and Hour. (L. M. T.)
Shioya	4° 55′ 49″	January 3 4h 31.7m p.m.
	4° 56′ 0″	,, ,, 8 4.3 ,,
	4° 56′ 28″	,, ,, 9 36.6 ,,
	4° 54′ 49″	,, 4 2 46.8 a.m.
	4° 55′ 39″	,, ,, 6 20.9 ,,
	4° 54′ 41″	,, ,, 8 16.0 ,,
	4° 54′ 52″	,, ,, 9 32.3 ,,
	4° 56′ 6″	,, ,, 10 32.6 ,,
	4° 57′ 34″	,, ,, 11 30.2 ,,
	4° 57′ 44″	,, ,, 11 34.1 ,,
	4° 58′ 57″	,, ,, 0 25.0 p.m.
	4° 59′ 34″	,, ,, 1 30.7 ,,
	4° 59′ 27″	,, ,, 2 17.2 ,,
	4° 58′ 27″	,, ,, 3 11.7 ,,
	4° 57′ 4″	,, ,, 3 56.9 ,,
	4° 56′ 22″	,, ,, 5 28.8 ,,
	4° 56′ 29″	,, ,, 6 12.9 ,,
	4° 56′ 33″	,, ,, 7 12.7 ,,
	4° 55′ 24″	,, ,, 9 18.9 ,,
	4° 54′ 47″	,, 5 1 59.5 a.m.
	4° 55′ 9″	,, ,, 4 46.6 ,,
	4° 54′ 32″	,, ,, 7 19.1 ,,
	4° 56′ 27″	,, ,, 8 29.9 ,,
	4° 57′ 29″	,, ,, 9 24.3 ,,
Isshiki	4° 22′ 18″	,, 8 10 24.9 a.m.
	4° 23′ 1″	,, ,, 11 5.9 ,,
	4° 24′ 32″	,, ,, 0 2.8 p.m.
	4° 25′ 49″	,, ,, 0 56.7 ,,
	4° 25′ 44″	,, ,, 1 59.4 ,,
	4° 24′ 58″	,, ,, 2 44.7 ,,
	4° 24′ 52″	,, ,, 3 26.4 ,,

Station.	Declination.	Date and Hour. (L. M. T.)
Isshiki	4° 24′ 38″	January 8 4h 8.0m p.m.
	4° 23′ 58″	,, ,, 4 51.4 ,,
	4° 23′ 28″	,, ,, 6 53.8 ,,
	4° 24′ 7″	,, ,, 7 46.1 ,,
	4° 23′ 47″	,, ,, 9 9.0 ,,
	4° 23′ 56″	,, ,, 10 54.6 ,,
	4° 24′ 10″	,, 9 6 39.8 a.m.
	4° 23′ 13″	,, ,, 7 38.6 ,,
	4° 21′ 38″	,, ,, 8 38.6 ,,
	4° 21′ 38″	,, ,, 9 31.1 ,,
	4° 21′ 30″	,, ,, 10 7.7 ,,
	4° 24′ 20″	,, ,, 0 4.4 p.m.
	4° 25′ 55″	,, ,, 1 49.8 ,,
	4° 26′ 37″	,, ,, 2 44.7 ,,
	4° 26′ 7″	,, ,, 3 34.7 ,,
	4° 25′ 15″	,, ,, 4 23.2 ,,
	4° 24′ 30″	,, ,, 5 0.3 ,,
	4° 24′ 33″	,, ,, 6 31.7 ,,
	4° 23′ 25″	,, ,, 7 25.8 ,,
Shimizu	4° 6′ 46″	,, 11 1 14.5 p.m.
	4° 6′ 46″	,, ,, 1 40.1 ,,
	4° 6′ 58″	,, ,, 2 33.5 ,,
	4° 5′ 34″	,, ,, 3 37.3 ,,
	4° 4′ 56″	,, ,, 4 23.6 ,,
	4° 4′ 31″	,, ,, 6 21.6 ,,
	4° 4′ 14″	,, ,, 7 35.5 ,,
	4° 3′ 42″	,, ,, 9 22.5 ,,
	4° 4′ 32″	,, ,, 10 33.5 ,,
	4° 4′ 13″	,, ,, 11 27. ,,
	4° 3′ 19″	,, 12 8 1.7 a.m.
	4° 2′ 49″	,, ,, 8 53.1 ,,

Station.	Declination.	Date and Hour. (L. M. T.)
Shimizu	4° 2′ 32″	January 12 9h 58.0m a.m.
	4° 2′ 44″	,, ,, 10 46.0 ,,
	4° 5′ 14″	,, ,, 11 48.8 ,,
	4° 7′ 18″	,, ,, 0 53.6 p.m.
	4° 7′ 12″	,, ,, 1 19.3 ,,
	4° 7′ 23″	,, ,, 1 47.4 ,,
	4° 7′ 19″	,, ,, 2 41.0 ,,
	4° 7′ 12″	,, ,, 3 15.2 ,,
	4° 7′ 14″	,, ,, 3 56.4 ,,
	4° 6′ 37″	,, ,, 4 24.4 ,,
	4° 5′ 57″	,, ,, 6 16.1 ,,
	4° 5′ 13″	,, ,, 7 11.5 ,,
	4° 4′ 59″	,, ,, 7 59.0 ,,

Dip.

Station.	Dip.	Date and Hour. (L. M. T.)
Numazu...	48° 29′4	December 21 1h 41m.8 p.m.
	48° 26′6	„ „ 3 7.3 „
	48° 30′6	„ „ 10 2.8 „
	48° 29′3	„ 22 8 34.4 a.m.
Hachiman-mura	48° 20′6	„ 22 4 24.9 p.m.
near Hamamatsu.	48° 21′1	„ „ 10 39.1 „
	48° 20′0	„ 23 9 14.4 a.m.
	48° 19′5	„ „ 2 3.2 p.m.
	48° 19′0	„ „ 9 36.8 „
	48° 20′7	„ 24 9 43.9 a.m.
Nagoya	49° 1′4	„ 24 7 55.4 p.m.
	48° 58′8	„ 25 8 9.8 a.m.
	48° 50′5	„ „ 3 19.8 p.m.
	48° 54′5	„ „ 5 16.3 „
	48° 49′5	„ „ 7 37.6 „
	48° 52′3	„ „ 8 13.9 „
	48° 51′3	„ „ 8 52.1 „
	48° 51′9	„ 26 9 33.9 a.m.
Nagahama	49° 13′9	„ 27 0 18.7 p.m.
	49° 13′3	„ „ 4 22.1 „
	49° 16′9	„ 28 10 30.6 a.m.
	49° 16′9	„ „ 11 15.2 „
	49° 11′7	„ „ 2 51.3 p.m.
	49° 12′5	„ „ 3 51.1 „
	49° 10′2	„ „ about midnight.
Obama	49° 23′4	„ 29 11 5.0 p.m.
	49° 26′3	„ 30 9 48.9 a.m.
	49° 22′7	„ „ 0 3.9 p.m.
	49° 22′8	„ „ 1 13.1 „
	49° 23′2	„ „ 2 3.6 „
	49° 22′6	„ „ 4 1.3 „

Station.	Dip.	Date and Hour. (L. M. T.)
Shioya	50° 22′0	January 3 5h 6m.4 p.m.
	50° 25′5	„ „ 6 16.5 „
	50° 23′2	„ 4 8 14.2 a.m.
	50° 26′5	„ „ 11 7.1 „
	50° 25′3	„ „ 2 48.7 p.m.
	50° 26′5	„ „ 5 58.3 „
	50° 26′8	„ 5 9 9.7 a.m.
Isshiki	48° 18′8	„ 8 10 51.4 „
	48° 19′0	„ „ 0 40.7 p.m.
	48° 14′4	„ „ 3 2.5 „
	48° 18′7	„ „ 4 29.8 „
	48° 15′0	„ „ 5 20.2 „
	48° 16′5	„ „ 5 54.2 „
	48° 16′7	„ 9 8 23.9 a.m.
	48° 14′3	„ „ 9 53.1 „
	48° 17′2	„ „ 4 12.2 p.m.
	48° 17′1	„ „ 4 48.9 „
	48° 16′2	„ „ 5 31.2 „
Shimizu...	48° 37′4	January 11 0 34.6 p.m.
	48° 36′9	„ „ 11 3.2 „
	48° 37′3	„ 12 8 30.9 a.m.
	48° 37′0	„ „ 10 29.7 „
	48° 36′6	„ „ 1 9.2 p.m.
	48° 37′4	„ „ 4 43.1 „

Horizontal Force.

Station.	Horiz. Force.	M.	Temp.	Date & Hour. (L.M.T.)
Numazu	0.30115	674.67	23°.03	Dec. 21 0h 0.7m p.m.
	.30073	677.54	14°.65	„ „ 4 45.8 „
	.30119	678.00	11°.09	„ „ 8 48.3 „
	.30089	679.72	8°.20	„ 22 7 48.5 a.m.
Hachiman-mura... near Hamamatsu.	0.30148	678.36	10°.73	„ 22 5 57.9 p.m.
	.30080	679.64	8°.25	„ „ 9 44.0 „
	.30116	677.77	11°.69	„ „ 3 41.3 „
	.30171	678.50	6°.85	„ „ 10 42.1 „
	.30188	677.83	6°.81	„ 24 8 56.8 a.m.
Nagoya	0.30148	677.85	4°.80	„ 24 6 45.0 p.m.
	.30107	675.60	9°.10	„ 25 9 28.2 a.m.
	.30136	672.16	16°.43	„ „ 11 45.0 „
	.30119	670.86	16°.23	„ „ 0 40.7 p.m.
	.30160	671.03	16°.12	„ „ 1 33.9 „
	.30122	671.93	14°.84	„ „ 2 21.4 „
	.30038	673.32	11°.13	„ „ 4 17.6 „
	.30131	675.06	8°.00	„ „ 6 47.6 „
	.30109	675.90	7°.53	„ „ 10 18.2 „
	.30120	676.44	6°.49	„ 26 8 45.1 a.m.
Nagahama	0.30081	672.13	13°.26	„ 27 1 13.4 p.m.
	.30100	674.83	9°.97	„ „ 6 10.2 „
	.30065	674.79	8°.54	„ 28 9 13.3 a.m.
	.30098	672.61	12°.23	„ „ 1 50.0 p.m.
	.30078	660.97	8°.73	„ „ 4 51.8 „
	.30096	662.43	3°.63	„ „ 10 1.8 „
Obama	0.30166	655.18	16°.66	„ 30 1 37.5 p.m.
	.30210	658.42	12°.03	„ „ 4 59.0 „
	.30268	655.42	12°.03	„ „ 9 57.1 „
	.30134	654.74	16°.72	„ 31 9 13.8 a.m.
Shioya	0.29648	658.96	6°.17	Jan. 3 9 4.8 p.m.
	.29696	659.01	8°.11	„ 4 7 11.9 a.m.

Station.	Horiz. Force.	M.	Temp.	Date & Hour. (L.M.T.)
Shioya	.29665	656.58	10°.99	Jan. 4 0h 11.9m p.m.
	.29646	656.81	10°.79	,, ,, 1 57.0 ,,
	.29650	657.81	7°.57	,, ,, 5 8.4 ,,
	.29670	658.37	7°.10	,, ,, 6 46.5 ,,
	.29632	659.02	4°.80	,, 5 8 7.6 a.m.
Isshiki	0.30294	656.90	11°.28	,, 8 11 43.5 a.m.
	.30260	657.55	9°.03	,, ,, 1 32.4 p.m.
	.30288	657.95	8°.38	,, ,, 3 51.7 ,,
	.30281	657.81	8°.14	,, ,, 8 30.9 ,,
	.30283	660.79	2°.07	,, ,, 7 22.2 a.m.
	.30313	658.17	8°.55	,, ,, 9 9.5 ,,
	.30284	656.61	11°.25	,, ,, 2 25.1 p.m.
	.30303	659.77	3°.93	,, ,, 7 6.2 ,,
Shimizu	0.30065	653.63	17°.21	,, 11 2 17.1 ,,
	.30058	654.35	14°.54	,, ,, 3 16.1 ,,
	.30097	659.02	6°.24	,, ,, 10 13.0 ,,
	.30072	657.54	9°.08	,, 12 9 10.1 a.m.
	.30048	656.02	12°.74	,, ,, 11 33.1 ,,
	.30056	655.60	12°.86	,, ,, 0 37.5 p.m.
	.30078	656.48	11°.50	,, ,, 3 41.9 ,,
	.30089	658.29	6°.25	,, ,, 5 3.6 ,,

Appendix.

Recalculated values of H for 1887.

Station.	Horiz. Force.	M.	Temp.	M_o.	Date & Hour. (L.M.T.)
Ishibashi	.29134	937.15	21°.0 c.	944.37	June 23 6h.00 a.m.
Yabuki	.28952	938.60	20°.4	945.54	„ 25 8.00 „
Matsukawa	.28784	937.78	20°.0	944.60	„ 26 7.00 „
Shiraishi	.28828	936.72	20°.1	943.58	„ 28 7.30 „
Shiogama	.28754	935.41	22°.6	943.21	„ 29 9.00 „
	.28720	933.79	22°.7	941.59	„ 30 6.00 „
Ishinomaki	.28778	936.53	21°.2	943.82	July 1 8.00 „
	.28745	937.28	22°.3	944.50	„ „ 5.30 p.m.
Ichinoseki	.28429	936.20	18°.0	942.65	„ 3 7.30 a.m.
Hanamaki	.28036	938.04	18°.4	944.28	„ 5 7.30 „
Morioka	.28179	937.26	20°.8	944.39	„ 6 8.00 „
Miyako	.27899	934.70	23°.2	942.76	„ 8 4.00 p.m.
Kuji	.27986	935.56	23°.4	943.67	„ 10 4.00 „
Hachinohe	.27688	937.02	22°.2	944.69	„ 12 8.00 a.m.
Gonohe	.27624	933.75	24°.3	942.24	„ „ 5.00 p.m.
Nobechi	.27579	934.52	24°.1	942.91	„ 13 6.00 „
Aomori	.27731	935.88	22°.7	943.73	„ 15 8.00 a.m.
Hakodate...	.27322	935.75	22°.3	943.19	„ 16 5.00 p.m.
Sapporo	.26768	931.52	25°.2	940.29	„ 19 5.30 „
Kiitup	.26677	933.83	23°.1	941.82	„ 24 4.30 „
Nemuro	.26047	931.86	26°.3	941.07	„ 25 4.00 „
Hirosaki	.27828	932.97	26°.3	942.19	„ 29 4.30 „
Ōdate...	.27741	935.34	20°.3	942.24	„ 31 6.00 a.m.
Nōshiro	.27857	930.85	31°.0	941.89	Aug. 1 4.00 p.m.
Akita	.28285	932.18	25°.2	941.00	„ 3 6.15 a.m.
Kariwano	.28231	934.50	26°.4	943.78	„ 4 6.30 „
Yokote	.28314	932.91	26°.4	942.17	„ 5 7.00 „
Innai	.28229	931.47	28°.0	941.35	„ „ 4.30 p.m.
Shinjō	.28530	931.43	27°.4	941.07	„ 7 7.00 p.m.
Sakata	.28472	931.94	27°.6	941.65	„ 8 7.00 a.m.
Yamagata	.28655	932.80	25°.4	941.63	„ 10 7.00 „

Station.	Horiz. Force.	M.	Temp.	M_0.	Date & Hour. (L.M.T.)
Yonezawa	.28833	931.28	30°.3 C.	942.04	Aug. 11 5.30 p.m.
Oguni...	.28756	933.58	21°.8	941.02	„ 13 7.00 a.m.
Nakajō	.28764	930.23	28°.3	940.20	„ 14 7.30 „
Ebisu...	.28987	923.57	35°.0	936.16	„ 15 noon
Niigata	.28704	928.32	28°.1	938.19	„ 16 7.30 a.m.
Kashiwazaki... ...	.28887	927.66	29°.7	938.17	„ 17 6.00 „
Sekiyama...	.29162	930.36	27°.1	939.83	„ 19 8.15 „
Ueda	.29636	936.59	21°.8	944.06	„ 21 6.00 „
Takanomachi ...	.29531	928.90	26°.6	938.19	„ „ 6.00 p.m.
Kōfu	.29282	926.19	35°.4	938.40	„ 23 4.30 „
Hara	.30146	929.69	25°.0	938.37	„ 25 6.35 a.m.
Hakone	.30514	929.16	25°.4	937.97	„ „ 5.00 p.m.
Ōtsu	.29674	927.19	29°.2	937.45	„ 26 5.00 „
Hōjō	.29641	927.85	27°.3	937.41	„ 28 6.00 a.m.
	.29632	926.75	29°.4	937.10	„ „ 4.00 p.m.
Katsuura...	.29622	929.20	25°.2	937.95	„ 29 5.30 „
Tōgane	.29534	929.22	22°.4	936.87	„ 31 6.15 a.m.
Chōshi	.29701	928.60	27°.0	938.02	Sept. 1 7.20 „
Kioroshi	.29381	930.46	25°.8	938.69	„ 2 7.00 „
Shimmachi	.29380	929.65	19°.0	935.86	„ 25 5.00 p.m.
Ōmiya	.29427	928.92	20°.1	935.73	„ 26 10.20 a.m.
Shimoda	.29992	442.80	20°.7		June 23 10.30 „
下田港海岸	.29992	442.68	21°.2		„ „ 3.13 p.m.
	.29967	440.43	21°.8		„ „ 8.21 „
Shimizu	.30166	441.45	21°.3		„ 25 afternoon
清水港波止場	.30022	442.65	21°.4		„ „ „
	.29971	442.45	26°.0		„ 26 2.10 p.m.
	.30016	440.72	25°.2		„ „ 4.31 „
	.29906	441.21	25°.1		„ 27 8.48 a.m.
Nagoya	.29880	442.17	26°.9		„ 30 9.02 „
名古屋師範學校新築地構內	.29840	441.93	29°.7		„ „ 11.44 „

Station.	Horiz. Force.	M.	Temp.	M_o.	Date & Hour. (G.M.T.)
Nagoya (*continued*)	.29988	441.37	24°.2 C.		June 30 h 6.26 p.m.
Kamiyashiro... ...	.30234	440.84	24°.7		July 4 8.46 a.m.
一色村鹽田中央臺場	.30198	441.15	26°.3		,, ,, 11.25 ,,
	.30199	441.37	24°.8		,, ,, 5.25 p.m
Nagahama	.30064	439.44	26°.8		,, 6 0.53 ,,
長濱舊城趾湖岸	.30033	440.31	25°.7		,, ,, 6.03 ,,
	.30019	440.07	24°.9		,, 7 9.02 a.m
Hyōgo	.30268	439.85	29°.3		,, 8 2.07 p.m.
吉田新田和田岬燈臺ヨリ凡五丁西	.30255	440.36	26°.5		,, ,, 4.48 ,,
	.30255	441.80	26°.4		,, 9 9.10 a.m.
	.30338	438.85	31°.6		,, ,, 1.20 p.m
Tokushima	.30731	436.82	27°.8		,, 10 6.51 ,,
安宅村蜂須賀氏別邸內	.30515	439.84	27°.3		,, 11 9.53 a.m.
	.30543	439.55	25°.2		,, ,, 0.10 p.m.
Kōchi.	.31094	435.95	27°.9		,, 17 0.16 a.m
高知字棒堤	.31043	435.98	29°.0		,, ,, 7.48 ,,
	.30842	438.34	31°.7		,, ,, 11.55 ,,
Minabe	.30437	438.90	31°.6		,, 21 9.57 ,,
南部北道村字濱端(舊臺場近傍)	.30484	438.51	31°.5		,, ,, 11.30 ,,
	.30486	438.12	32°.8		,, ,, 2.55 p.m
	.30494	438.74	30°.7		,, ,, 5.56 ,,
Okayama...	.30418	438.16	31°.4		,, 26 9.00 a.m
中野村宗忠神社前新道東端	.30430	437.71	34°.2		,, ,, 1.28 p.m
	.30446	437.86	33°.0		,, ,, 5.07 ,,
Hiroshima	.30713	438.02	34°.15		,, 28 0.41 ,,
病院付屬地庭中池ノ南岸	.30674	437.82	35°.2		,, ,, 4.13 ,,
	.30734	440.34	25°.0		,, 29 6.32 a.m.
	.30688	440.21	26°.9		,, ,, 7.35 ,,
	.30650	439.45	29°.9		,, ,, 8.37 ,,
	.30683	438.43	34°.15		,, ,, 9.32 ,,
	.30702	437.60	35°.75		,, ,, 10.31 ,,

Station.	Horiz. Force.	M.	Temp.	M_o.	Date & Hour. (L.M.T.)
Hiroshima (*continued*)	.30697	437.22	37°.0 c.		July 29 ^{h}11.35 a.m.
	.30719	437.38	36°.0		„ „ 0.32 p.m.
	.30695	437.37	36°.2		„ „ 1.38 „
	.30716	437.22	35°.75		„ „ 2.32 „
	.30724	437.74	35°.1		„ „ 3.32 „
	.30685	438.44	35°.3		„ „ 4.35 „
	.30711	438.20	30°.5		„ „ 5.32 „
	.30694	439.22	29°.0		„ „ 6.47 „
Wakwan (Korea)...	.30421	438.94	31°.9		Aug. 6 10.06 a.m.
日本人居留地西町四丁目松林西館	.30463	438.13	32°.7		„ „ 1.39 p.m.
	.30472	439.33	27°.6		„ „ 5.19 „
Mēho (Korea) ...	.30667	439.78	26°.8		„ 11 6.34 a.m.
落東江口流中洲	.30592	438.59	32°.8		„ „ 11.01 „
	.30673	436.76	36°.1		„ „ 2.08 p.m.
Pusan (Korea) ...	.30893	437.89	29°.2		„ 13 10.56 a.m.
釜山城北河原	.30915	436.07	34°.3		„ „ 2.23 p.m.
	.30897	437.44	29°.2		„ „ 4.06 „
Kurosaki...	.30605	436.82	32°.6		„ 15 11.24 a.m.
Shiinokijima... ...	.30514	437.83	28°.3		„ „ 6.40 p.m.
Fukuoka...	.31011	437.40	30°.5		„ 22 7.44 a.m.
福岡監獄署裏舊臺場	.30988	436.55	32°.5		„ „ 10.40 „
	.30986	435.95	34°.0		„ „ 3.24 p.m.
Nakatsu	.30975	435.53	35°.8		„ 24 1.26 „
中津城北海濱	.30978	436.04	34°.9		„ „ 4.23 „
	.30983	437.69	28°.8		„ 25 8.27 a.m.
Saganoseki	.31086	437.24	30°.7		„ 28 8.23 „
關村伽藍堂跡	.31102	437.03	32°.5		„ „ 11.10 „
	.31146	436.94	30°.4		„ „ 3.37 p.m.
Hichiyamura ...	.31356	436.74	31°.4		„ 29 3.49 „
日知屋村字春町	.31334	438.37	27°.8		„ 30 8.07 a.m.
	.31362	436.70	34°.0		„ „ 10.45 „

Station.	Horiz. Force.	M.	Temp.	M_o.	Date & Hour. (L.M.T.)
Miyazaki...	.31587	437.30	31°.4 c.		Sept. 1 8.53 a.m.
江平町師範學校躰操場	.31565	436.67	32°.9		,, ,, 9.31 ,,
	.31552	436.33	34°.8		,, ,, 10.12 ,,
	.31528	436.20	34°.6		,, ,, 10.51 ,,
	.31512	436.27	34°.8		,, ,, 11.31 ,,
	.31518	436.27	34°.8		,, ,, 0.11 p.m.
	.31564	436.33	34°.0		,, ,, 1.30 ,,
	.31569	435.40	34°.5		,, ,, 2.10 ,,
	.31533	436.22	33°.8		,, ,, 2.50 ,,
	.31533	436.45	33°.35		,, ,, 3.31 ,,
	.31588	436.31	35°.15		,, ,, 4.12 ,,
	.31561	436.84	31°.6		,, ,, 4.49 ,,
	.31555	437.20	29°.6		,, ,, 5.29 ,,
	.31521	437.70	28°.35		,, ,, 6.09 ,,
Yatsushiro	.31477	436.52	32°.6		,, 6 10.48 a.m.
八代町陸軍墓地	.31496	436.81	31°.8		,, ,, 4.20 p.m.
字若宮	.31458	436.42	31°.5		,, ,, 9.33 ,,
Nagasaki...	.31369	435.32	35°.9		,, 10 9.43 a.m.
波止場東巡査講習場					
Hagi	.30857	436.42	32°.2		,, 13 11.20 ,,
濱崎海岸字菊ヶ濱	.30902	437.03	29°.4		,, ,, 0.48 p.m.
	.30874	438.00	26°.1		,, ,, 4.18 ,,
Hamada	.30023	438.14	26°.0		,, 16 4.32 ,,
原井村市中畑	.30022	440.06	18°.9		,, 17 7.12 a.m.
	.30046	436.68	31°.2		,, ,, 11.21 ,,
Matsue	.29993	437.96	26°.5		,, 20 1.04 p.m.
縣廳裏城內	.30014	437.91	26°.0		,, ,, 4.55 ,,
	.29992	440.25	19°.9		,, 21 7.00 a.m.
Imaichi	.30008	438.14	24°.2		,, 22 8.53 ,,
今市橋渡村字御前	.30019	437.49	29°.3		,, ,, 11.40 ,,
今市ヨリ西凡十丁	.30018	438.29	25°.7		,, ,, 5.14 p.m.

Station.	Horiz. Force.	M.	Temp.	M_o.	Date & Hour. (L.M.T.)
Kanōmura	.30175	439.14	21°.9 c.		Sept. 25 h 0.09 p.m.
邑美郡叶村字中島河原土堤	.30186	439.31	20°.9		,, ,, 4.42 ,,
	.30120	441.22	14°.7		,, 26 7.20 a.m.
Koyamamura ...	.29971	438.21	24°.3		,, ,, 1.51 p.m.
湖山村東北二丁計綿畑	.30971	438.45	21°.9		,, ,, 5.07 ,,
	.30003	438.74	21°.3		,, 27 7.54 a.m.
	.29962	437.16	28°.7		,, ,, 10.26 ,,
Maizuru	.30079	438.27	25°.3		,, 30 11.49 ,,
舞鶴城趾小學校運動場	.30108	438.92	21°.5		,, ,, 4.45 p.m.
	.30118	440.34	16°.8		Oct. 1 7.07 a.m.
Obama	.30006	438.13	24°.7		,, 2 11.34 ,,
小濱臺場跡	.30047	438.82	21°.2		,, ,, 4.33 p.m.
	.30006	440.66	16°.8		,, 3 8.00 a.m.
Shioyama	.29536	437.82	26°.9		,, 4 0.02 p.m.
鹽屋浦小學校裏一丁計	.29566	437.76	26°.0		,, ,, 4.58 ,,
	.29550	439.00	20°.6		,, 5 7.26 a.m.
Nanao	.29398	440.62	16°.8		,, 8 9.05 ,,
七尾字出崎加州海軍所跡	.29381	440.13	19°.2		,, ,, 0.59 p.m.
	.29424	439.26	20°.6		,, ,, 4.38 ,,
Tōkyō (W)	.29678	438.13	25°.4		Nov. 8 11.52 a.m.
帝國大學運動場	.29661	437.71	25°.4		,, ,, 1.39 p.m.
	.29659	439.75	17°.1		,, ,, 4.20 ,,
,, (E)	.29634	438.99	19°.7		,, 10 9.29 a.m.
	.29644	438.66	22°.1		,, ,, 1.01 p.m.
	.29619	440.30	16°.8		,, ,, 4.15 ,,

Optical Note.

K. Takizawa.

If one observes a Newton's ring apparatus through a thin film of mica, several sets of rings are seen in those parts of the field, where if white light is used, ordinary Newton's rings are not found. Each group consists of a middle dark ring with two concentric white rings next the dark one, and several colored rings outside and inside. Besides these prominent groups, a group of faint rings is observed inside the first group. All sets are concentric with each other and the space between any two sets is devoid of rings. The diameters of these rings depend on several conditions. The thinner the mica film, the smaller the diameters. The greater the air film of the Newton's ring apparatus, the smaller the diameters. The effect of inclining the film so as to receive the light from the Newton's ring apparatus more obliquely is equivalent to using a thinner film. All these phenomena can be very easily explained by the ordinary elementary theory of interferrence.

As to the existence of these rings, it is well known that the rings are invisible in those parts of the field, which correspond to a great thickness of the air film, because the lights of maximum and minimum intensities are very nearly equal in their wave-lengths for a given direction. If we examine a small portion of an ordinary Newton's ring (which is invisible in white light) by a prism, a large number of dark bands are seen in its spectrum. If we bring the dark middle ring of the first prominent, group as seen by a mica film (let us call

it the group A) into the centre of the field by increasing the thickness of the air film, so as to form a central dark spot, and examine the spectrum of a small portion of it by a prism, we observe a series of dark bands between which there is a series of curved dark bands. The straight bands are those formed by the mica film, and the curved ones are those formed by the Newton's ring air film. The dark central ring of A is formed, because the lights of maximum intensity through the air film are the very ones which are of minimum intensity through the mica film. The reason why the bands are curved, is obvious. If we form a white central spot by an approach of A toward the centre, the straight bands coincide with curved bands, so that lights which are as a minimum after interferrence through the air film, are still minimum after the interferrence through the mica. Hence no change is produced by the mica film. After a few colored rings, whose formations can be readily understood after the above explanations of the formations of dark and bright rings, there is a space of uniform illumination. And then a second group that may be called the group B, very similar to A is seen. Here again in the middle dark ring, the lights of maximum intensities through the air film are minimum by the interferrence through the mica. If a central dark spot be formed of the dark ring and its spectrum examined, we again see a series of straight and curved bands, but this time the number of curved bands are twice as many as straight ones. And one of the straight ones coincides with one of the curved ones in the middle part of the latter. If a central white spot formed by white rings of B group be examined, the two curved ones fall neither on the curved dark bands nor on the part just mid-way between two bands, corresponding to the light of maximum intensity, but between the two, so that the light of maximum intensity passes through the mica. Whatever be the order of the group, in the middle

dark ring the light of maximum intensity is made minimum by mica and in the white rings, the straight bands are not in the middle part between any two dark curved bands. Five groups were well observed, and groups of a higher order might be observed by means of thinner mica. It is needless to say that air films corresponding to the central dark bands A, B, C, &c. are in the ratio of 1, 2, 3, &c., as is proved by the fact that the squares of the diameters of the dark rings are in the same ratio.

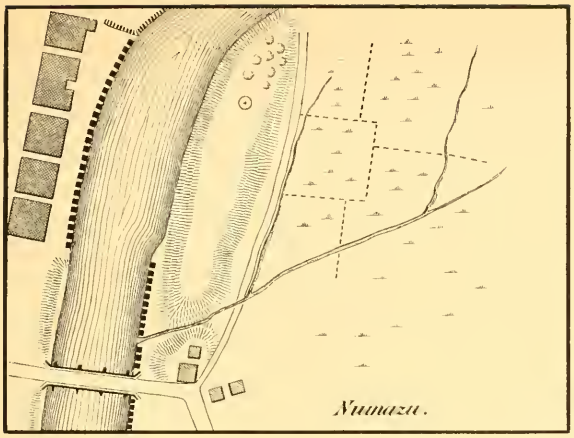
The difference of march between once and twice reflected rays by the air film corresponding to the middle dark band of A together with the loss of $\frac{1}{2}\lambda$ is precisely equal to that introduced by the mica film, as is shown by the fact that the dark band produced by the air film lies mid-way between the two bands produced by the mica. Hence the thinner the film, the nearer is the group A to the centre of the system.

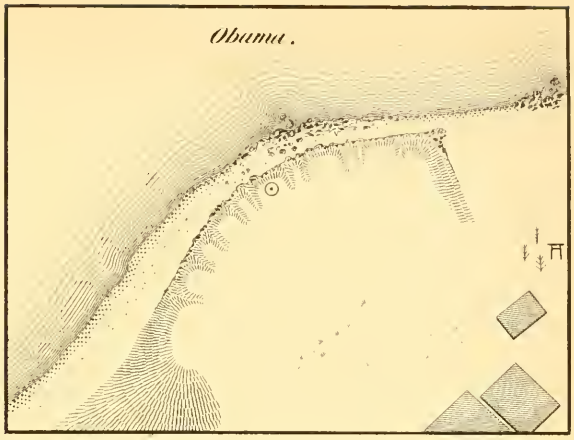
In the faint rings, the difference of march introduced by the air film corresponding to the dark middle ring is greater than that by the mica film by $\frac{1}{2}\lambda$. Hence if we could observe its spectrum, there would be twice as many straight bands as curved ones, but I was not able to observe it on account of faintness.

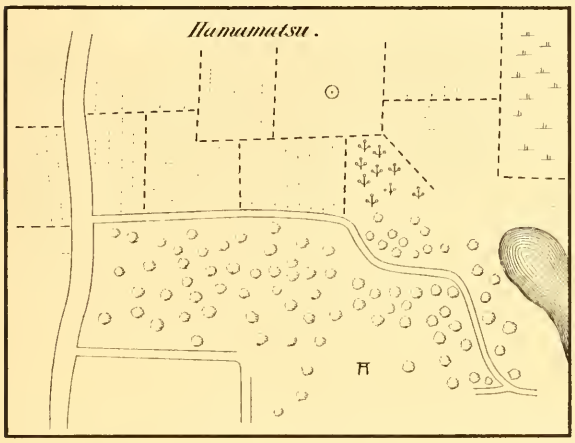
The effect of inclining the mica film so as to receive the rays more obliquely is equivalent to thinning the film as regards the difference of march introduced. Hence if the group A is not seen within the field on account of too great a thickness of the mica film, it can be seen if the film is held obliquely.

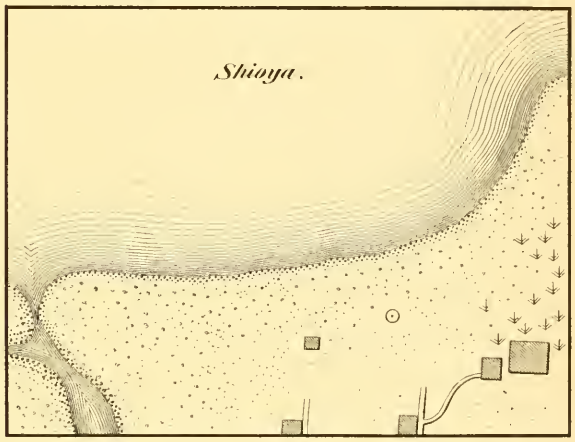
The groups are also well observed by reflected light from the front surface of the mica film. It is needless to say that the appearances are complementary.

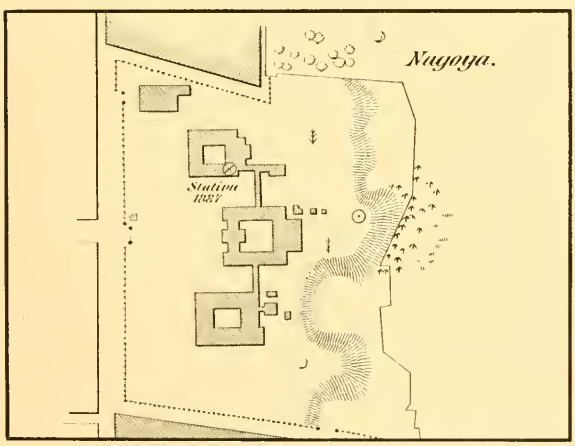
In conclusion, it may be stated that the phenomena described are in no way peculiar to the mica film. Any thin film can be used. The same phenomena were observed by means of a thin air film between two achromatic prisms. The observation of course, much more difficult than with a mica film.

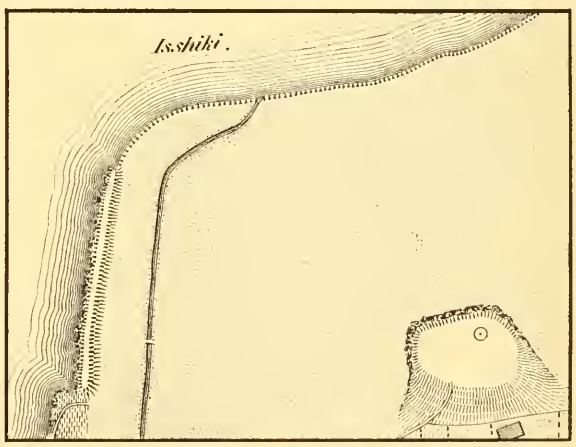


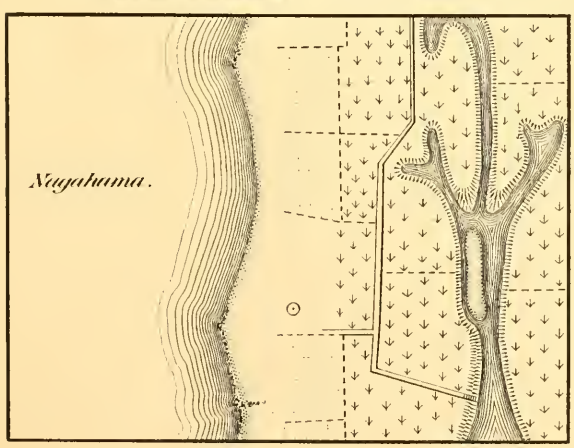


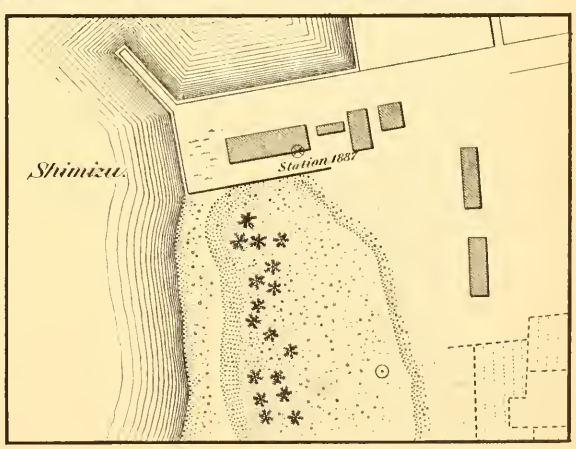












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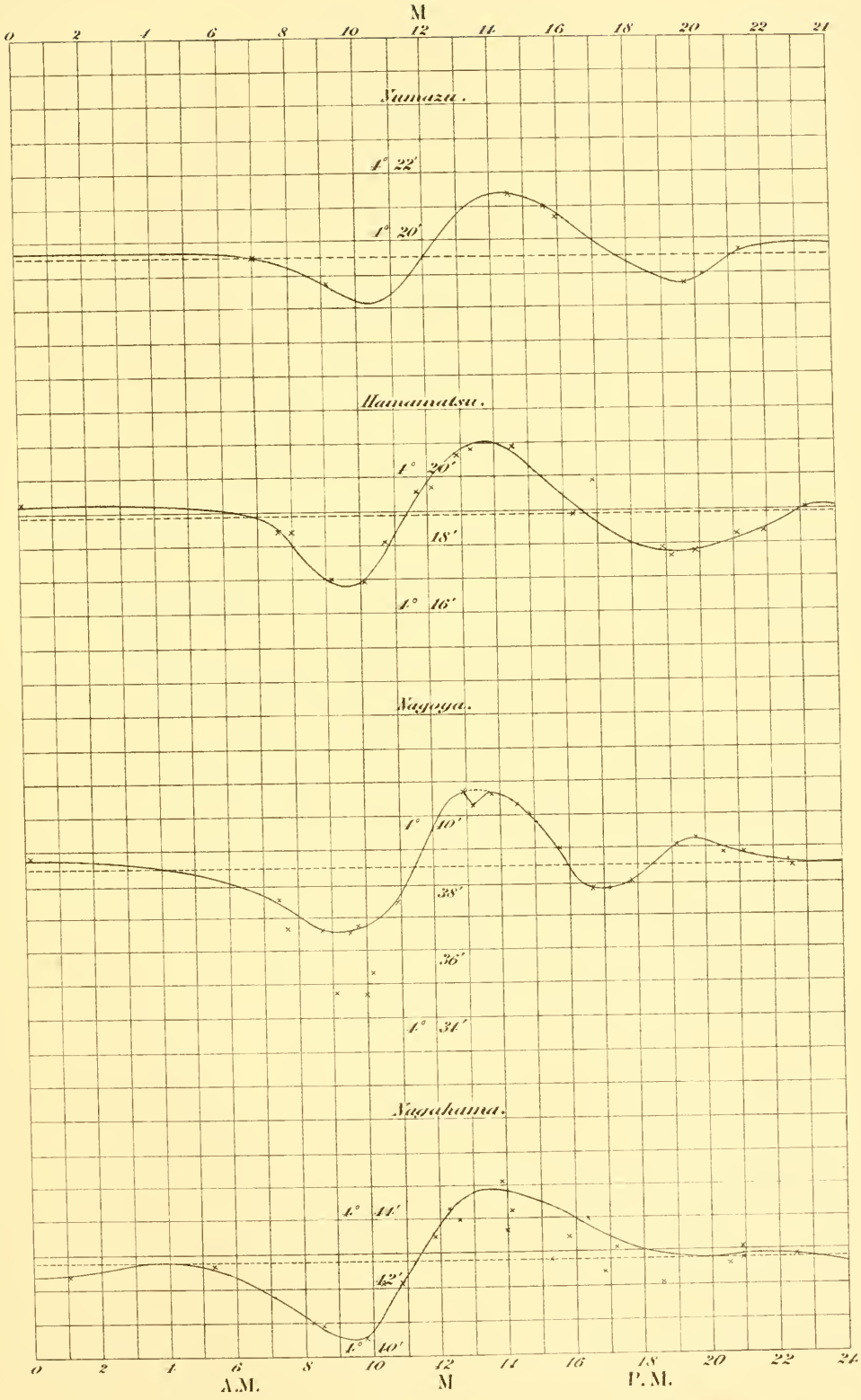

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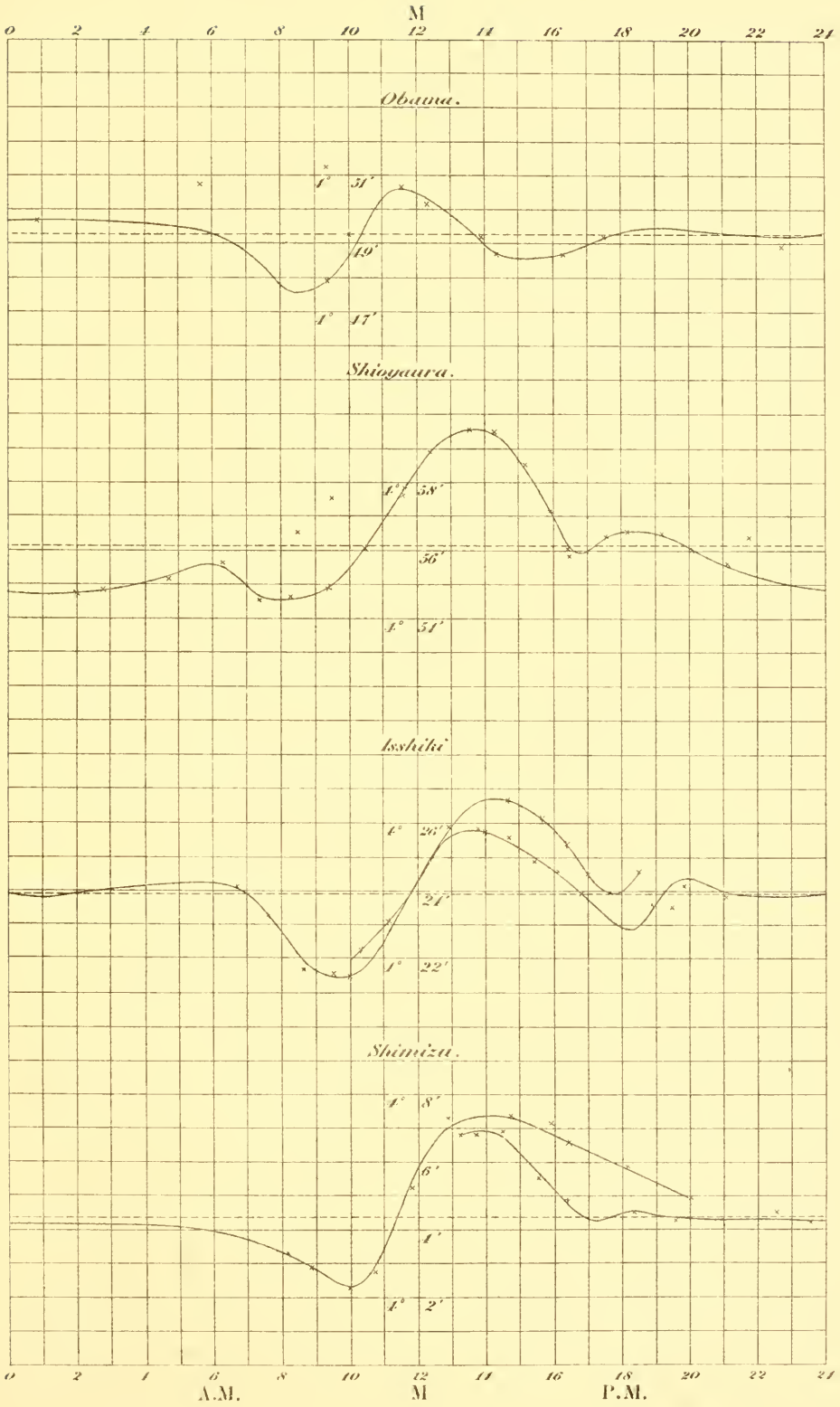

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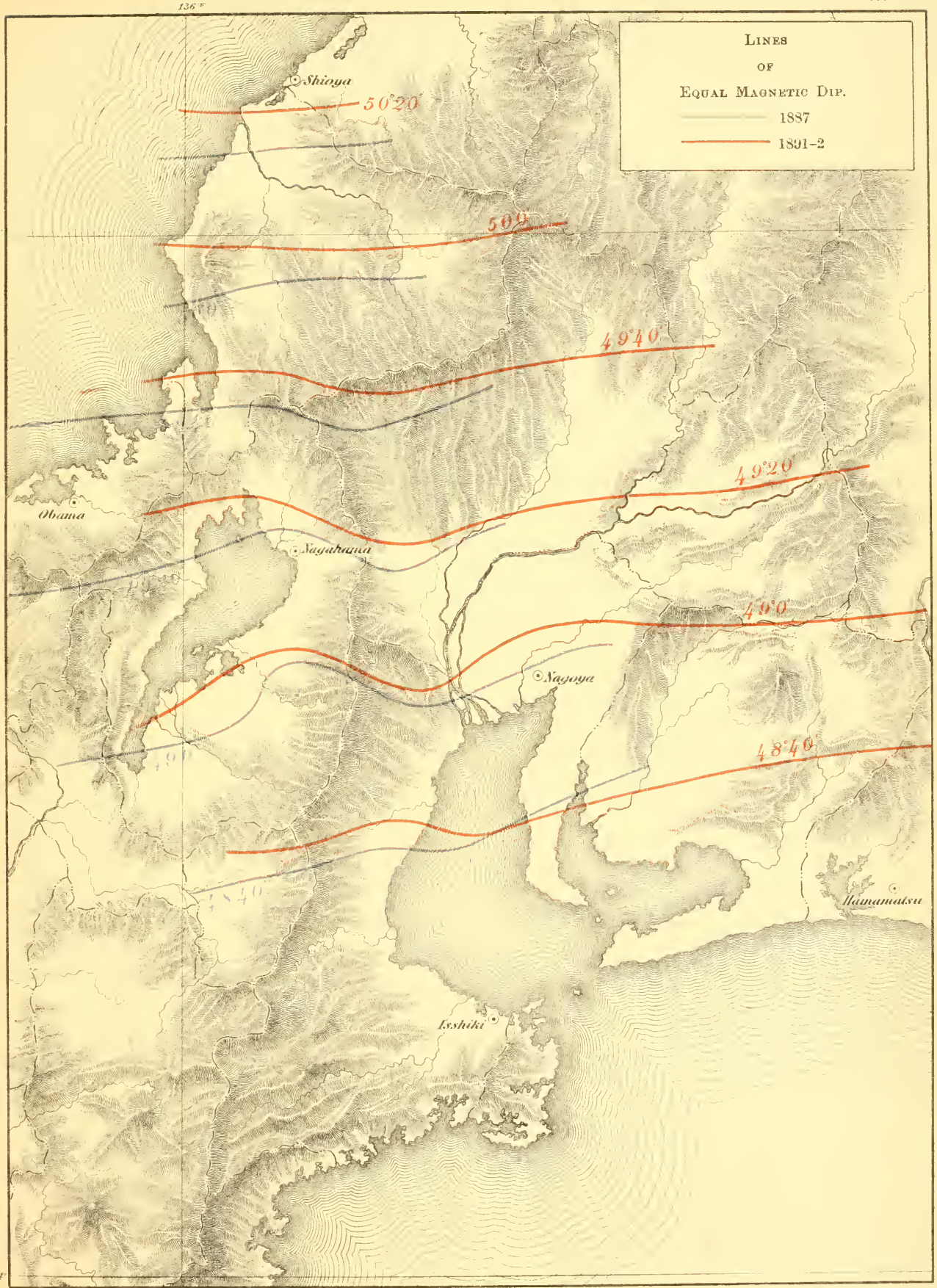

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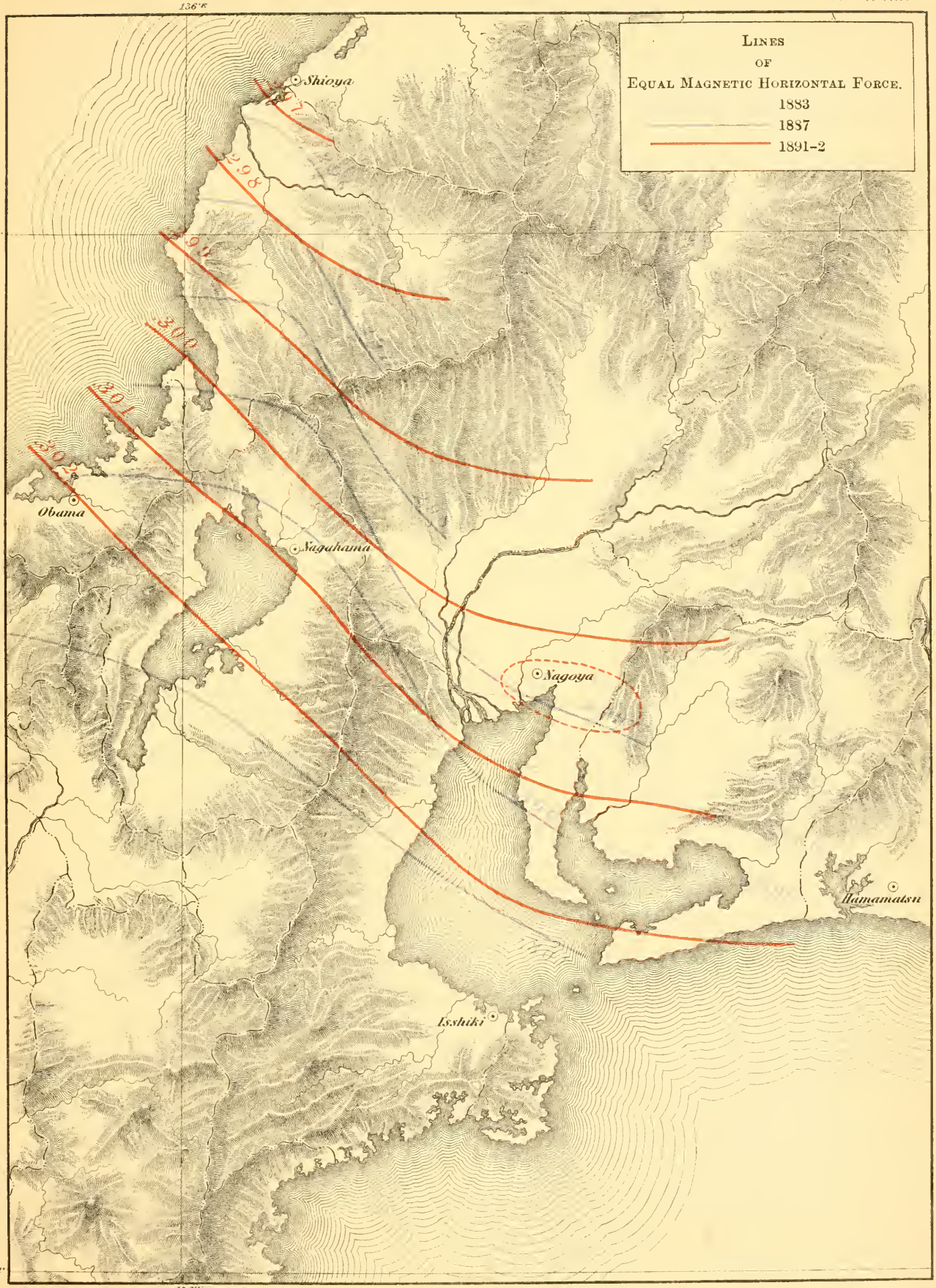

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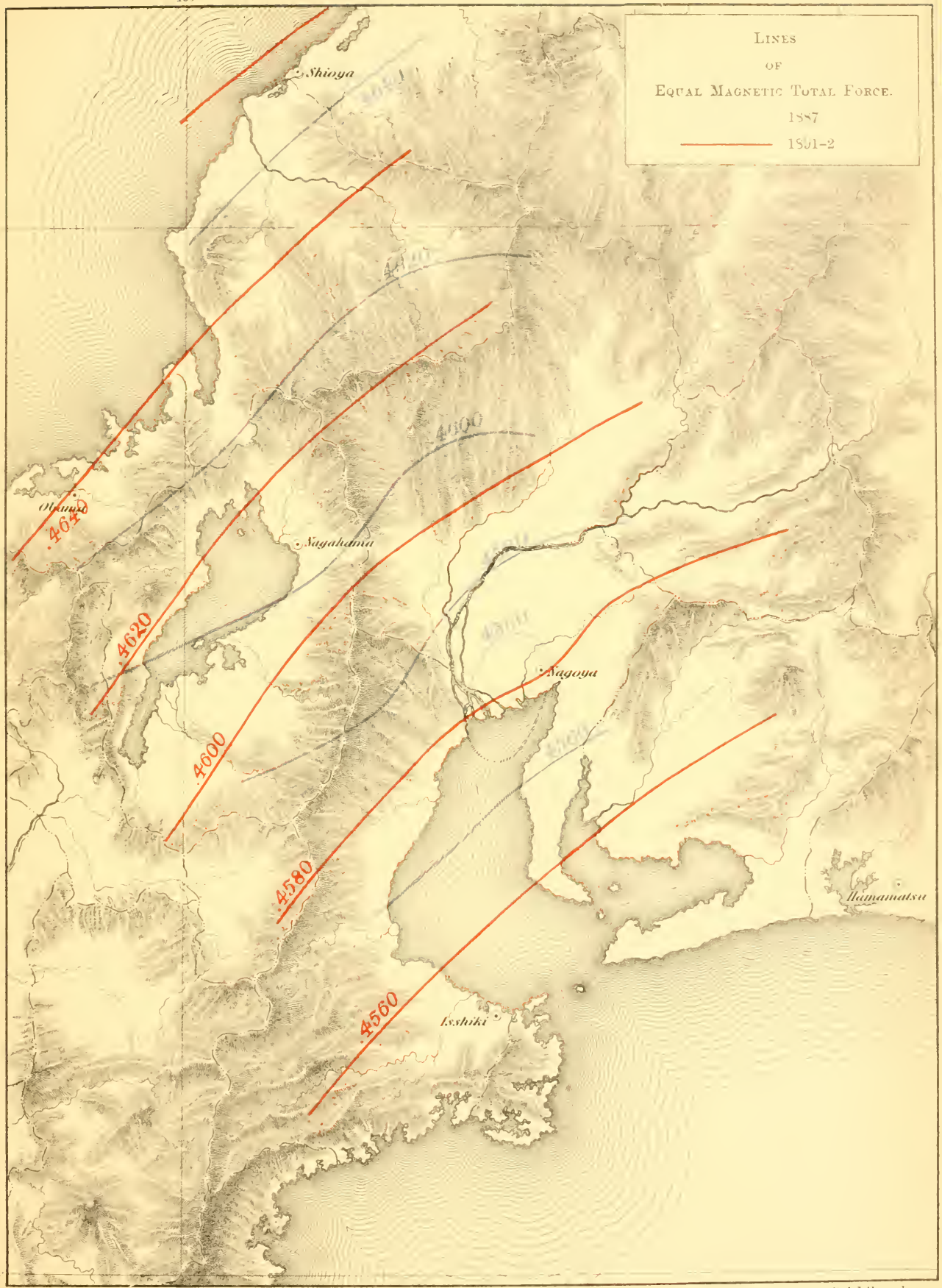

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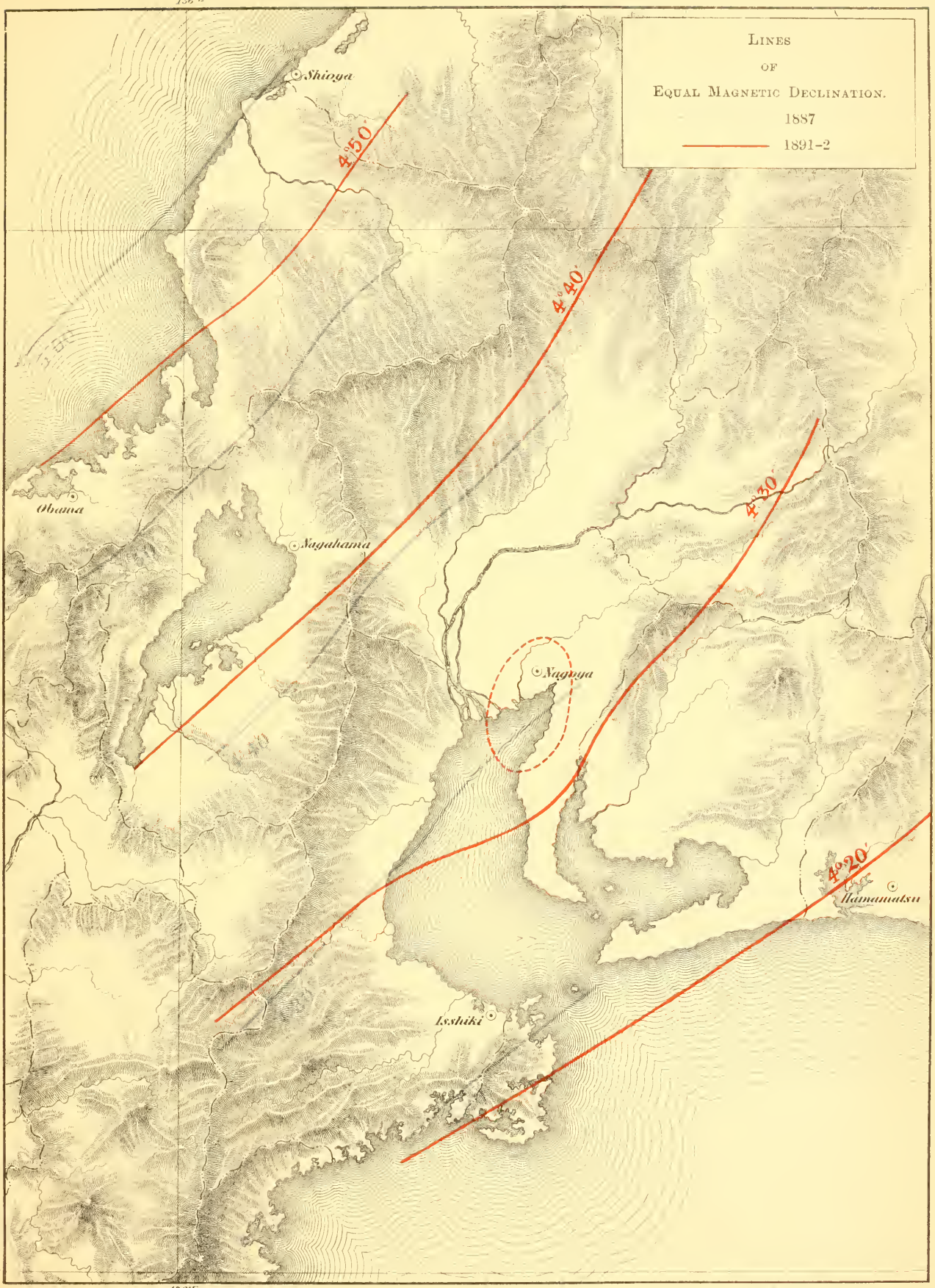

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ERRATA.

By inadvertence of the photographer, the numbering of the figures in Plate XXVI was put in wrong order.

For " Fig. 1 " read " Fig. 4." For " Fig. 2 " read " Fig. 3."

For " Fig. 3 " read " Fig. 2." For " Fig. 4 " read " Fig. 1."

Also 11th line from the top, in the Explanation of Plate XXVI, for " lower " margin read " upper " margin.

Page 243, 7th line from the bottom, for " Fig 7 " read Fig. 10."

Page 246, 11th line from the botton, for " fcldspar " read " feldspar."

Page 256, 13th line from the top, for " *weckenjörmig* " read " *weckenförmig*."

The Archæan Formation of the Abukuma Plateau.

By

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With Plates XXII-XXVII.

I. Introduction.

Dr. Edmund Naumann, in his excellent little work *Ueber den Bau und die Entstehung der japanischen Inseln*, has proposed a primary division of all Japan into Northern and Southern, by a remarkable, great, geotectonic line, a "*fossa magna*," which, as he says, traverses the whole breadth of the Main Island, from the Pacific Ocean to the Japan Sea.

In spite of a controversy that has arisen between Dr. Naumann and Dr. Harada, as to the existence or non-existence of that geologic moat, it must nevertheless be admitted that that division is in every way a most satisfactory one. The South was the cradle of our civilization, while the North was, down to the middle ages, the home of the Ainos. The climate of the South is sunny and mild, being influenced by the warm, genial Kuro-shiwo that washes the Pacific coast; while the North is chilly, for the polar current runs close by the shore.

That geotectonic line is also approximately the boundary of the vegetation of the *north subtropical zone*,[1] or the zone of *Pinus Thunbergii*, and *Ternstroemiaceæ* are rarely found to the north of that limit. Thus, from various sides, geologically, historically, and climatically, as well as phytogeographically, this line serves as the boundary for the great natural division of the Empire.

North Japan begins from the east side of the Hakoné mountains, running straightforwards, in almost meridional direction, towards Hokkaidō; and along its Pacific side is to be seen a relic of a once gigantic Archæan realm, though disturbed in various ways. Between this pre-palæozoic band and the backbone of the island, longitudinal and radial valleys have been scooped out, those of the Abukuma-gawa, Toné gawa, Naka-gawa, and, lastly, of the Kuji-gawa.

The south end of the above-mentioned Archæan belt has been briefly sketched out by the present writer in one of his former papers,[2] *On the so-called Crystalline Schists of Chichibu*; the present one is an instalment of the results accruing from several occasional trips, since made in the northern prolongation of the same belt, *i. e.*, the Abukuma Plateau.

II. The Abukuma Plateau.

Proceeding northwards from Mito, in the province of Hitachi, once the resident-town of the princes of the same name, through Hamakaidō or the coast-road of Iwaki, to the mouth of the Abukuma, we there get a tolerably good view of the physical features of the plateau. The scenery is simple, but grand; the thickly wooded, precipitous escarpment faces the sea, with an approximately meridional

[1] M. Fesca, Beiträge zur Kenntniss der japanischen Landwirthschaft, Allgemeiner Theil, Karte der Vegetationsgebiete, Tōkyō, 1890.

[2] This journal, Vol. II., p. 79.

trend. The general aspect vividly reminded me of the Sambagawan chain of Shikoku, as viewed from the Seto-uchi side. Below, down the steep declivity towards the plain, the precipitous wall is flanked on the east by the palæozoic sandstones and clayslates, which gradually submerge themselves under the tertiary and still later formations; the surface deposits of the lower plain, or rather of a raised beach, being a thick accumulation of granitic blocks and coarse sand.

The superficial covering of diluvial deposits, just referred to, is mainly composed of sand and gravels, with little or no clay that might keep hold of the percolating waters. Being of such a coarse and porous texture, the dry soil is no better than the pumice ground of Nasu, or the region around Volcano Bay in Hokkaidō. For this reason, we find here many lonely "haras," or prairie-like ground, 2-4 km. in breadth, along the shore, such as the Hara of Sōma, Harano-machi, and Chūka.

These sterile flats, together with the underlying tertiary strata, terminate abruptly at the water's edge, forming precipitous bluffs, interrupted only by occasional indentations of alluvial depressions.

The region lying to the west of these grassy deserts is the elevation of Abukuma. It extends over the provinces of Hitachi and Iwaki, stretching north and south for about 150 km. with an average breadth of 45 km. It is separated from the backbone of North Japan by the meridional valleys through which the rivers Abukuma and Kuji make their way; and its north and south sides are limited by these streams, which, after making an easterly trend, finally discharge their waters into the Pacific basin. The general outline of the plateau thus defined is consequently elliptical.

The *physical aspect* of the elevation presents a typical physiognomy of a plateau-character, with the mean height of 400 m. It is a broad, gently undulating surface, relieved only by some few promi-

nent points, the highest being the Yomogita-yama (933 *m.*), with abrupt bluffs along main drainage-channels, usually in an east and west course. The hilly table-land faces the Pacific sea-board, as already mentioned, with a steep escarpment five to six hundred meters down to the plain below. On the west the slope is scarcely perceptible, and the plateau merges gradually in the fertile valley of the Abukuma river; only in a few places is the fall very marked.

The field of my study does not comprise the entire plateau, but is chiefly confined to that portion between the cities of Taira and Tanagura (Plate XXII). As the stratigraphy of the Archæan formation of this country has not hitherto been systematically worked out, it was my desire to know something of the sequence of superposition of the schistose series; and this point I have always had in mind during my trips. On the other hand, I cared but little about the topical distribution of special groups of rocks and their reciprocal boundaries, leaving these details to the mapping geologist, Mr. Ōtsuka, who is now prosecuting the field-work of this region.

III. Archæan Geology.

General Statement.

The Archæan rocks of the Abukuma plateau, like those of other parts of the world, are separable primarily into two main divisions, viz.: an upper, chiefly schistose, bedded; and a lower, of the granitic, dioritic, or syenitic type of mineralogical composition, but more or less gneissose in structure. In the (*a*) *upper* division there can be recognized at least two leading groups. One of these is developed in full advantage on the way from Taira to Takanuki, through the narrow gorges of Gozaisho. The other is found in its typical form in the region lying to the west of the former, and occurs

between the base of the Gozaisho rocks and the Laurentian. The present paper is the first attempt that has ever been made to classify the oldest rocks within the confines of the Japanese islands. Being unable to correlate the series of the upper division with any with which I am acquainted in the geology of China and Corea, I propose now to name the first group the *Gozaisho series*,[1] the second the *Takanuki series*.[2] In the (*b*) *lower* division distinctions of stratigraphical sequence and relationship, if any such ever existed, have been obliterated. For this assemblage of rocks, viz., the lower division of the Archæan, the well-known term *Laurentian*, so named from the Laurentian Mountains in Canada, and not from the St. Lawrence River, is retained.

The leading divisions of the Archæan for this region may, from what has been stated, be arranged in the following scheme, according to the order of which the geological features of the region will be considered in detail:—

Archæan..... { *Upper division.* α. Gozaisho series.—(Huronian?)
β. Takanuki series.
Lower division.— Laurentian.

A more comprehensive statement of the results arrived at, will be given in the summary, after the facts, upon which these and other generalizations are based, have been set forth.

IV. Stratigraphical Relations and Structure Sections.

Having sketched briefly the general aspect of the plateau, and pointed out my aim, I may now consider the stratigraphical composition of the series. It was found that it is usually disposed in

[1] 御在所 菊多郡, 磐城國 [2] 竹貫村, 東白川郡, 磐城國.

sharply folded troughs and in extensive, detached masses by frequent intrusions of all sorts of younger and older granites, which through horizontal pressure assume at times a gneissose structure. I have selected for discussion a number of lines of section where the whole complex so far as represented is favourably exposed. The first of these sections,[1] A-B in Plate XXV, is that lying furthest towards the south, and is taken along the road that joins the small port of Hirakata on the east, and Kawakami in the Kuji valley, for a distance of 24 km.

From Hirakata to Yamagoya, the road gradually ascends through paddy-fields. At Yamagoya, ochry sandstones and grey shales make their appearance, with thin seams of lignites which seem to be of tertiary age, as is indicated by the presence of a few fossil plants,[2] such as *Sequoia Langsdorfii* Brgt., *Juglans nigella* Hr., *Juglans acuminata* Braun., *Carpinus* sp., *Acer* sp., *Vitis* sp. This is underlaid discordantly by a black, coarse, massive rock (G B) with the aspect of a gabbro, covered with red soils and "niggerheads." As is usually the case, excellent exposures of this rock were not found, such as to disclose the relation with the adjacent complex. Under the microscope it is a typically coarse-grained rock, consisting of hornblende and feldspar, with but few remains of augite. The feldspar is grey, contains a number of rods, arranged in some determined direction, and is said to be the cause of schillerization, as is explained by Prof. Judd. The light-yellow augite occurs detached within the hornblende in the form of grains, as if it had been absorbed by the latter—a phenomenon very common in gabbro-diorites. Through weathering a portion of the feldspar has been removed, and the black components come into relief, so as to produce almost a slaggy aspect.

[1] The positions of this and other sections are indicated by thick lines, with corresponding letters on the map, in Plate XXII.

[2] Explanatory Text (Japanese) to Section Kitsuregawa, published by the Geological Survey of Japan.

Next comes a peculiar, black rock (P Y), of massive appearance and more or less schistose in structure. It is almost entirely made up of large hornblende-individuals with some traces of feldspar and augite. This is evidently part of the gabbro-diorite, crushed and compacted to the present form, and accompanied by a new formation of hornblende, which occurs in lenticular spaces with tolerably perfect crystallographic outlines. How this is related to the diorite is as yet unknown to me. If this relation were thoroughly examined, some light might be thrown on the genesis of schistose hornblende rocks, which are of wide distribution in Abukuma and elsewhere.

The gabbro diorite re-appears from Yōjigata as far as the place called Hirasodé, interrupted at its middle by a mass of hornblende-granite. On ascending the Hanatate pass to Saimaru, we see again the hornblende-granite, often containing detached masses of titanite-hornblende schist[1] and also small fragments of it (marked × in the profile), which produce the appearance of a breccia, cemented by a granitic material. The whole is frequently traversed by yellowish, fine-grained aplitic or pegmatophyritic dykes. The included amphibolite dips towards N. E. with the strike of N. 45° W.

We then proceed westward from Saimaru, through a thickly wooded, steep ascent of the Nakayama pass, locally known as "Nakayama Sanri," and finally come to the top, beyond which an interesting series of the Archæan schists may be seen. It is mainly an alternation of (*a*) the titanite-hornblende schist, (*b*) mica-schist, and (*c*) gneiss-mica schist; the second often approaching both in its composition and appearance to a true quartz-schist in losing either biotite or muscovite. The whole complex is included by the present writer under the *Takanuki series*, and considered by him to be the oldest

[1] This is the rock that largely enters into the composition of the upper horizon of the Takanuki series.

member of the upper Archæan group of Japan. Special descriptions of these rocks are given in another chapter.

As may be clearly understood from the profile, the whole of the Takanuki series is pinched in between hornblende-granite, and this fact serves as an example of undoubtedly irruptive granite, having literally taken up with it a part of the crust of the earth in its bosom, whatever may have been the nature of the irruption, whether passive or active.

As the schists are flanked on both sides by irruptive matter, and as all dip at very high angles, we can roughly estimate the breadth of the *lower member* of the Takanuki to be 5 km. We do not here take into account the thickness of the upper member, *i. e.*, the titanite-amphibolite (U T A), which makes up only an insignificant part of the section.

At Yama-no-Ogawa the gabbro-diorite (G B) again makes its appearance as a large boss. From here to the village of Kawakami, we find nothing but the hornblende-granite (H G), variously intruded into by the younger biotite-granite (B G) and pegmatophyritic dykes (*d*). Near the last-mentioned village, the hornblende-granite assumes a gneissose structure (G H G) with the strike north and south.

The second line of section selected, C-D in Plate XXV, is one drawn westwards from Kadōno, 12 km. west of Taira, across the ridge of Gozaisho to the west of Takanuki. This is the best profile one can get of the whole region, as the line goes approximately across the strike of the complex, which embraces nearly the complete series of the Archæan rocks to be studied, excepting the upper horizon of the Takanuki series. It is interesting chiefly as showing the stratigraphic relation in a clear manner in favourable exposures found along the transverse valley through which the brawling Samé-gawa makes its course ; and one of the ways of communication across the plateau

is cut out of the rocks along the left bank of the river. This road we call the "Gozaisho dōri."

The basal member lies in a somewhat elevated portion of the plateau (Takanuki, 315 *m.*) on the west, while the eastern half of the section comprises the younger series. The bedding of the rocks is always disturbed, and that of the Gozaisho complex in particular, wherever it can be detected, as is frequently the case, is vertical. If we take into consideration, however, the enormous jamming together which the rocks have undergone, we can easily imagine as a result the complete parallelism of all the structural planes, affording a false appearance of a continuous section at right angles to the plane of deposition. Hence it is not safe to infer much from a twenty-three kilometers section of schists as to the original normal thickness. It is evident, however, that such thickness must have been enormous. The right half of the section, grouped together by me in one series as the *Gozaisho rocks*, seems to be tolerably free from great and irregular disturbances, and to be all tilted up in vertical position; and of these schists I venture to advance figures for the thickness, which is probably not less than 10,000 meters.

The thick mass of the Gozaisho schists terminates on the east near Kadōno, being there covered by nearly horizontal layers of the tertiary shales and sandstones. At no great distance from this spot, brown coals are now being profitably worked in the same bed. At Negishi, a greenish, fine-textured, rather massive schist crops out along the banks in a vertical position with a slight inclination towards the east. It has the aspect of a clastic rock, and is like a hardened deposit of volcanic ashes, with here and there, not infrequently, white, garnet-bearing quartzite (marked Q in the section C-D).

This is followed to the west by alternate bands of green and white schists, intruded into at times by a hornblende-granite (H G).

From near the Gozaisho temple, the green schists become more fissile, and intercalated with a black mica-schist (marked M.) To the westward, in the vicinity of the district-boundary of Higashi-Shirakawa and Kikuta, the green schists gradually disappear and give place to a black, crystalline hornblende schist, which occupies the basal portion of the series. The thick complex of schists which we have hitherto traced from Kadōno to Ishizumi is very persistent and monotonous in character throughout.

Having briefly considered the lithological succession of the voluminous, schistose hornblende rocks, of which the whole gorges and the solitary ascents of the Gozaisho road are composed, I shall add a few words on their nature. These rocks strike north and south dipping eastwards with very high angles, and being usually on end, or vertical. Such being the case, it is quite impossible to form a definite idea as to the sequence of superposition within short distances; but viewing the whole series at large, I cannot help thinking that those lying eastwards must be stratigraphically younger than the schists on the west.

The rocks at the west end of the Gozaisho Narrows, consequently the lowest of the present series, bear, as I have already had occasion to note, the unmistakable physiognomy of a genuine crystalline schist. They are laminated, perfectly fissile, evenly planed; in short, they present none of the signs that would show them to have been formed from some antecedent rock or rocks through metasomatic and paramorphic changes so profound, that their original characteristics would have been effaced beyond recognition. But the higher we ascend towards the horizon, the rocks become less fissile in structure, appear more compact and elastic, and eventually pass into a green slate, made up

apparently of the ashes and mud of volcanic ejectamenta, subsequently changed to the present form through varied dynamic metamorphism. It is practically impossible to draw a hard and fast line between the varieties they present; but altogether they form a lithological continuity and a harmonious whole, although, when their extremes are compared side by side, they appear at first sight to have nothing in common with each other. As I have elsewhere pointed out, it is very interesting to note that at the higher horizon are found the light-coloured and rather hard, more compact and chloritic varieties, resembling an altered trap; while the less hard, perfectly fissile schists crop out at the basal portion. The gradual changes which are observed between multifarious varieties appear to be due to the operation of some cause, of the nature of which nothing certain can be at present made out.

I am not bold enough to assert freely that such basal, crystalline members are the dynamo-metamorphic products of massive, syenitic or dioritic rocks, crushed and remodelled to the present form, as has been done by many great authorities, who claim excessive and profound effects for pressure-metamorphism. For them there are properly no gneisses and mica-schists, but those derived by pressure from massive rocks. Taught by the modern school of dislocation-metamorphism, I was at first misled, while travelling through the Abukuma plateau, last summer, to consider the amphibole schists, and even the gneisses and mica-schists to be crushed products; the first derived from dioritic and syenitic rocks, the second and third from granites. But gradually I became convinced that *at least a part of the hornblende schists of the Gozaisho series is of primary origin* (though its exact mode of formation remains unknown), *and not a product of the crushing effect of a mass-movement of the earth's crust.*

In this connection, something may conveniently be said on the mode of formation of those gneisses and schists that come below the *Gozaisho complex*, and which are now included by me in the *Takanuki series* and the *Laurentian*.

There are in this region numberless modifications of granites, syenites as well as gabbros, that are more or less schistose. This once seemed to me an invincible circumstantial evidence of the crushed-rock origin of schists and gneisses, and apparently harmonized well with all the facts, then observed in the field. But being unwilling to come to a hasty conclusion, I visited the plateau again during the last Easter-holidays, and this time I found some of my former conclusions to be illusory. There are of course *schistose granites*, spoken of usually, though very improperly, as granite-gneiss or gneiss-granite, which are really connected with the massive granite of irruptive origin, and these I consider to be of the age of Laurentian. There are again, *forming another group*, *gneisses and mica-schists*, at one time included by me without distinction in the same class as the Laurentian gneisses. They are intercalated between bands of a coarse crystalline limestone, near Takanuki, for example.

Overwhelmed by the array of facts continually presented to my eyes during field-work, I paid little heed to the interbanded limestones, which besides give little hope of affording fossilized remains. Now, Reyer says, in his *Theoretischen Geologie*, that carbonate rocks may reasonably occur inserted between granites through interrupted up-welling of a plastic magma by subsequent pushes (*Nachschub*). Examining closely the mode of occurrence of these rocks, I found the schistose granite to be really granite (Laurentian) with that special structure, due surely to the effect of pressure; while the limestone-bearing gneiss, and the mica-schist (Takanuki series), both having a distinct parallel arrange-

ment of component minerals, are, so to speak, primary rocks, and should not be confounded with the foliated granite. The two classes of rocks are quite distinct in origin, and are not issues from a common stock of granite. No geological continuity is ever found between them; on the contrary, the Laurentian granite and the foliated granite intrude into the overlying, genuine gneisses of the Takanuki series. Good exposures of their contact will be frequently mentioned when explaining the profiles in the sequel.

We now return to the section which we left at Ishizumi, in Gozaisho.

Going westwards for a short distance, we arrive at the upper edge of the rapids, whence the Samé-gawa takes a narrow and swift course down from the plateau to the lowland, which lies further to the east. Here is the boundary of the districts, Higashi-Shirakawa and Kikuta. As may be clearly understood from the profile (C-D), the above mentioned Gozaisho series are brought to a sudden close by an outcrop of granites. The massive rocks are dome shaped; the peripheral, schistose hornblende-granite with its enclosed patches of the titanite-amphibole schist has a schistose plane which here dips eastwards with high angles, but on the other side has westward inclinations. The nuclear part is a young biotite-granite (M G) with much quartz and less mica; this hard rock hangs over the deep gorges of the Samé-gawa.

The rock which we first meet with in coming from the east is the ragged form of an old hornblende-granite, over which the road makes many crooked turns. It is a schistose modification of that granite. Examined under the microscope, it is seen to be made up of biotite, hornblende, plagioclase, orthoclase and, lastly, quartz. Biotite and

hornblende, are present in about equal quantities; oligoclase, but little; clear, well-finished apatite, abundant. The orthoclase shows well-marked undulatory extinctions, and is remarkable for the zoning. The nuclear part seems to differ greatly in chemical composition, as may be seen from the usually decomposed state of its interior. It is a syenitic or dioritic granite. Misled by its rudely schistose structure, I once looked upon it as an intermediate stage between syenite and the amphibole schists of the Gozaisho series; and then thought I might be able to trace the gradual passage from one extreme to the other. During my second visit to this district, however, I discovered a spot where the amphibolite comes in direct contact with the schistose granite, the former being sharply cut by the truly irruptive granite with schistose structure, well exposed on an abraded cliff at the water's edge. Looked at from a distance a marked contrast in colour and structure soon suggests something quite heterogeneous, and on close examination the junction is still very clearly defined, the effusive granite cutting in obliquely, independent of the schistose plane of fissile rocks, while the latter is often convulsed and caught up in pockets within the granite. This, therefore, affords most conclusive evidence as to the heterogeneity of the adjoining rocks as regards genesis.

Having thus traced out, as closely as field conditions will allow, the limiting edges of the granitic boss and the Gozaisho series, we may now proceed to examine the mode of occurrence of the underlying Takamuki series to the westwards. The last-mentioned complex is widely separated by the irruptive mass, of which we have already spoken, from the overlying Gozaisho series, and this holds true of other sections which we have had occasion to study. The two series of the Upper Archæan are, therefore, always separated, so far as I am aware at present, by the intervention of some foreign mass, usually granite; and no line of their direct contact has been ever

observed either in Abukuma, or in the upper course of the Tenrū-gawa in the province of Shinano.

The *Takanuki series* is so named from a village in the vicinity of which that complex is typically developed. The whole series is divisible into two parts: the (α) *upper* (U T A), embracing the multifarious alternations of the titanite-amphibole schist and biotite-gneiss; the (β) *lower* (L T A), being composed of a thick mass of various gneiss-mica schists and gneisses. The occurrence of the lower subdivision has been already alluded to in examining the line of section of the Nakayama pass,[1] where the beds stand vertical, but dipping in the peripheral portions of the series towards the middle point, so as to produce a fan-shaped structure of the Mont Blanc type. Here, however, the schists make a low arch with their main axis in the north-south direction, and the line of section runs obliquely across the strike of this dome-shaped mass.

The rock first met with in coming westwards from the granitic area of the district boundary is the upper member, which forms a small synclinal at Shimo-Matsukawa, and is intruded upon by another boss of hornblende-granite. At Shimo-Matsukawa we find still the titanite-amphibole schist (U T A) with a dip towards the east at low angles; and not far from this point, the lower member (L T A) finally makes its appearance, keeping the same dip and strike as the upper. A highly quartzose, brownish, granulitic gneiss, accompanied by a micaceous schist with plenty of garnet, is found all along the road for a distance of 6 km, until we come to the west of Takanuki. Often the whole complex has been so disturbed, in various ways and at numerous points, by the intrusion of biotite-granite, as to make one almost believe the granite to be

[1] See p. 203.

a normal member of the gneiss-mica schist, petrographically somewhat similar to it. At Kami-Matsukawa, the schists are nearly horizontal with a dip towards the north at very low angles, and just at the west end of Kami-Matsukawa, a highly coarse-crystalline limestone, about 70 cm. thick, is interbanded between the granulitic schist, having the strike W. 20° N. and dip 30° N. E. At Kamada we meet again with the titanite-amphibole schist, now with the strike N. 40° E. and dip N. W.

The line of section, E-F, Pl. XXV, from the small hamlet of Kami-Misaka to Ishikawa, is very similar in general features to the sections A-B, and C-D. But here only a part of the *Gozaisho belt* (G Z) is to be seen, for a distance of not more than $\frac{1}{2}$ km. in breadth, flanked on either side by a granitic boss. The lower member of the *Takanuki series* is concealed from view in the present line of section, owing probably to a great dislocation line, whose southern prolongation at the west of Takanuki may be traced in the last profile; and this fault has probably brought the upper member in direct contact with the granite.

As may be seen from Fig. 8, Pl. XXIV, the above mentioned small belt of the Gozaisho rocks at the east end of the profile, is pinched in between granites B G and H G, and consequently the mode of arrangement is very much disturbed. Near a small water-mill at Naka-Misaka, a tourmaline-bearing *hornblende-salite schist* (*b*) of a rather black, massive appearance seems to abut against the neck of an amphibole-picrite (*d*), but the exact relation between them could not be made out. The *peridotite* is, on the east, in direct contact with the hornblende-granite, which is itself more or less gneissose in structure (*gn*) near the line of contact. The peridotite is followed, to the west, by bands of spotted chlorite-schist, alternating with a garnet-chloritoid-quartz schist (*c*), said to contain the unique mineral

piedmontite,[1] which is of very wide distribution elsewhere in Japan, especially in the island of Shikoku. The chlorite schists are followed by another band of platy epidote-amphibole slate (*a*), which is tilted up in vertical position like the overlying rocks, and is partly corrugated at its junction with the biotite-granite (B G), indicating that the latter has broken through the former, and brought it to its present form.

Beyond the small ridge of Komori-zuka[2] (574 m.), the hornblende-granite makes its appearance, often interrupted by a later eruption of the biotite-granite, and also by the formation of aplitic dykes (*d*). Between Jūmoji and Kodaira, we meet with a detached mass of the titanite-amphibolite (U T A) of tolerably large dimensions. This soon gives way to the hornblende-granite, which is more or less gneissose (G H G), with the plane of schistosity inclining towards the east, having just the same dip as the last-mentioned patches of amphibole schist. At Nakagura the granite has acquired a peculiar habitus (Nakagura type), owing to the predominance of somewhat large grains of quartz, which gives to the rock a blotchy appearance. Farther to the west the line of contact of the granite with schists is observed, in which the irruptive nature of the former through schists is clearly marked. Not far from the line of contact, a dyke (L P) of about 2 m. thickness is found in a vertical cleft. The material of the dyke is of a dark-greyish colour with brown spots. Microscopic analysis, the details of which are given in a separate section, proves it to be an augite-dioritic lamprophyre.

From Nakagura to Sōri, through Ōtsuka and Nakata, the rocks exposed are multifarious alternations of thin bands of titanite-amphibole schists, and gneiss-mica schists (U T A). Of the amphibole

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[1] This journal, *Some Occurrences of Piedmontite in Japan*, Vol. I. p. 303; also *On the so-called Crystalline Schists in Chichibu*, Vol. II. p. 93.

[2] See the line of section E-F, Pl. XXV.

rocks we have to mention as chief varieties the *titanite-biotite amphibolite*, *titanite-salite amphibolite*, *titanite-feldspar amphibolite*, and lastly, *biotite-amphibole gneiss*. Those of the second category show the following modifications, viz., the *gneiss-mica schist*, *two-mica schist*, *garnet-biotite schist*, and also *hornblende-biotite schist*. The whole complex has been variously faulted in parallel lines, giving rise to a so-called stair-case structure ; at other times horizontal pressure seems to have produced a compressed arch. Again, in one case at Ōtsuka, a mass of hornblende-granite must have been squeezed along a fault-line, considerably disturbing the adjacent rock on the east, while on the other side schists seem to overlie conformably the granitic basis (Fig. 7, Pl. XXIV). This boss affords an excellent example of the schistosity of a granite. The peripheral portion is highly gneissose in structure in conformation to the surrounding rock, and little by little it gradually passes to a normal granular variety at the centre. How such structure has been brought about is not an easy question to answer. It may perhaps be the result of a crushing during epigenetic movement of rocks, or may have been produced, as Reyer[1] assumes, during upwelling of a semi-fluid magma by constant pushes (*Nachschub*), by lateral compressions.

The amphibolites and gneisses, lying to the east of the last-mentioned irruptive mass, have acquired a specially great fissility, cleaving easily into a papery slab ; and owing to its loose texture, the rock falls into a bluish-black, ashy-looking powder on weathered surfaces.

The structure of the Archæan belt at this part is undoubtedly a very complicated one, as has been suggested in the foregoing lines. The rocks are mostly brought to a vertical position, or dip at angles rarely less than 80°, with the strike of N. 20° W. Considering their present position as a result of pressure, the recurrence of

[1] loc. cit.

the same zone in the section is by no means unlikely. But, making a small deduction for the breadth of the eruptive rock and a correction for the dip, we can estimate the probable thickness of the formation, and this was found to be $5\frac{1}{2}$ km. for the upper horizon of the Takanuki series.

At Sōri, where the road bifurcates, one leading to Takanuki, the other to Kodaira, an important tectonic line was accidentally discovered. Here an insignificant isoclinal valley comes from the east, through the villages of Kodaira and Nakagura, along which the present line of section was drawn. A precipitous wall on both sides of the rivulet is wholly composed of alternate bands of the titanite-amphibole schist and the two-mica schist ; all of them dip westwards at very high angles with the strike north and south. A ridge along the west side of the valley, forming a naked whitish precipice, at once gives information of its being composed of a granitic material, contrasting greatly in colour and habitus with the black, schistose rock of the opposite side (Fig. 11, Pl. XXIII)[1].

If we adopt the view of the excessive effect of dislocation-metamorphism, and in accordance with it attribute the formation of banded gneisses and amphibolites to the crushing of dioritic and granitic rock by strong pressure, it is not yet easy to conceive of such sudden changes of structure at so short a distance. Therefore, I examined very closely the spot where possibly the line of junction of the schists and granite might occur high up on the cliff ; and in doing so, I found actually the place where two geological bodies of entirely different origin come in direct contact, side by side, having nothing in common either in appearance or structure. The granite is the hornblende-bearing variety with an imperfectly schistose structure and its plane of schistosity inclining towards the west ; and the streaky,

1 In Fig. 11, Pl. XXIII, Nakagura valley is erroneously spelled as *Nagura*.

lenticular nodules of a dioritic habitus, produced by differential movement of a granitic magma, dip with their longer axis towards the same point. The complex of amphibolite and mica-schist has also the dip in the same direction; but it is sharply separated from the other by a nearly perpendicular line of fault, which seems to continue southwards for a long distance, with the bearing N. 30 E.

From what has been said, it is evident that the granite and schists are geologically different bodies, brought to their present situation side by side by a down-thrust of the schistose member, and *they are by no means structural phases of one irruptive stock.* Although the section now examined seems at first sight quite insignificant, and to have no bearing of geological importance, nevertheless it has been of great use to me, by showing clearly the two sets of rocks to be of heterogeneous origin. Some gneisses and amphibolites approach in their outward aspect to the schistose modification of granites, and confounding them together is very liable to occur during field-work. This in itself is to a certain extent reasonably allowable, but it would be a gross error to consider the two kinds of rocks as different phases of primarily only one species of rock. For some distance to the west, the same schistose granite with streaky nodules continues to appear along the road as far as Ishikawa, where it gradually passes into a normal granular variety, containing likewise blackish nodules of a more or less dioritic habitus. We see here a number of reddish, fine-grained pegmatophyre dykes (*d*), running N. 30° E. with N. W. dip.

The last line of section (G-H) that will be examined is drawn from Ishikawa to Shimo-Kawabe on the right bank of the Abukuma-gawa. This traverses the region from S. E. to N. W., and stretches for about 6 km. The chief interest attaching to the present section is not, however, in the bedded formations of the series, but in the irruptive rocks which, mixing with each other, cause a very complicated tectonic

condition. The effusive rock that comes here into consideration is mainly granite. It is to be separated into an *older*, hornblende-bearing (H G), and a *younger*, biotite-bearing (B G) variety. They intermingle with one another in such a confused manner as to try the patience of even careful observers ; and many have entirely ignored the heterogeneous origin of the two kinds of massive rock (Fig. 1, Plate XXIV).

On the way from Ishikawa to a small height where the road ascends towards Shibukawa, we meet with the continuation of the granite-mass, already referred to in the preceding profile. In one spot a mass of dioritic habitus occurs of tolerably large dimensions. Examined under the microscope, it is found to be mainly composed of feldspar and needle-shaped hornblende, with a little biotite and orthoclase. Macroscopically it approaches in its external aspect to the so-called "needle-diorite" (marked × in the section). Not far from this point, another exposure of a similar kind makes its appearance in a road-cutting. Blackish dioritic patches of various sizes are enclosed in normal hornblende-granite, as if a dioritic scum had floated on a granitic paste, and then been torn asunder by some movement in the semi-fluid mass. The patches seem to have been once a part of the same granitic magma, slightly different in chemical composition (Fig. 8, Pl. XXIII). These should not be confounded with the caught-up fragments of amphibolite in hornblende-granite, or the hornblende-granite in biotite-granite, as the enclosed and enclosing rocks in the latter two cases differ both in age and composition, and the patches have angular outlines.

Just on the top of the hill, two large dykes (*d*) traverse the granite in the E.-W. direction. The material of the dykes is a pegmatic mineral aggregate with large orthoclase crystals twinned on the Baveno type. Large, opaque biotite, smoky quartz, and muscovite are other ingredients of this aggregate. A dull, brownish beryl is said to have been found in it.

The rest of the region represented in the section is entirely composed of old and young granites, which appear successively along the lines of fault after the manner of ruin-marbles. Sometimes aplitic dykes traverse the rocks irrespective of the nature of the granite. The hornblende-granite assumes at times a gneissose structure in the usual manner, as is indicated on the west end of the section G-H. From Nakano a quartz-bearing augite-andesite covers the eroded edge of the underlying rock. Near Shimo-Kawabe (*i*), fleams of a hornblende-biotite gneiss of the lower member of the Takanuki series are enclosed within the mass of hornblende-biotite granite of schistose structure, and the whole is traversed by coarse pegmatic dykes (Fig. 5, Plate XXIV).

V. Petrography of the Laurentian Rocks.

Generally speaking, the granites of the extensive region of Abukuma may be classed in two categories; the *first group* is a rather greyish-looking, medium-grained variety, in which the long prisms of hornblende (8 mm.), and the broad, hexagonal scales of biotite could be easily recognized within the admixture of the white ingredients of the rock. It is hornblende-granite. To the *second group* belong those common, coarse-granular granites of a lighter colour, built up of a flesh-coloured orthoclase, and a grey, vitreous, allotriomorphic quartz, mixed with black mica.

These two groups differ greatly in many respects; the grey rock contains, as is usually the case, more of the plagioclases when compared with the light-coloured rock, although none of the last named rock is free from the presence of the striped feldspars. The most common rock of this region is undoubtedly hornblende-granite. It may be seen all over the district wherever exposures of granites are to be

found, being often cut sharply by wide dykes of the *biotite-granite* in a most confused manner, as is represented in Fig. 1, Plate XXIV. Therefore the biotite-granite must be of later age than the hornblende-bearing variety. When such dykes of the younger granite appear repeatedly within a short distance it is often not easy to say which is the foreign mass and which the intruded one. It is not necessary to point out the localities of such occurrences, as these perplexing cases are inevitably met with during field-work.

A. Amphibole-Granites and Biotite-Granites.

The dominant rock of the region, the amphibole-granite, has, as is already stated, a very uniform composition which varies only through local fluctuations in quantity of the several ingredients. All the rocks included under the present group contain, therefore, *quartz*, *orthoclase*, *microcline*, *plagioclase*, *amphibole*, *biotite*, *titanite*, *apatite*, *zircon*, and *opaque iron ores*. To these may be added the usual, secondary accessories, such as *epidote*, *chlorite*, *muscovite*, and *iron-glance*.

Before we enter into the detailed description of the individual occurrences of granites, it may be well to speak of the minerals which enter into the composition of the rocks. Although their properties do not differ in essential points from those of other granites, still it seems well to give here some consideration to them as likely to prove of some use for the mapping geologists of our Geological Survey.

The *feldspars* are of three varieties, viz., orthoclase, microcline, and plagioclase. The secondary muscovite, resulting from decomposition, is common to all of them ; while epidote is very rarely observed, indicating that the plagioclase is of an acid nature, and consequently poor in lime. In regard to dimensions, there occur large and small individuals which, although belonging to the same generation,

still differ a great deal in size even in the same rock. The orthoclase and plagioclase are both of large dimensions; but the latter is the smaller of the two feldspars, and is idiomorphic in comparison with the monosymmetric variety, while the microcline is usually of an allotriomorphic form, and is the latest in its formation[1] and the smallest in its size.

The *orthoclase* is a greyish-white form, usually devoid of well-defined crystallographic outlines; it becomes flesh-red in slightly decomposed specimens. In the field, observers might be easily misled to consider such an orthoclase to be a different variety, and consequently would make a quite distinct type by calling the rock which contains it a red granite in contradistinction to the common grey one; but in truth both form one and the same mass. As already stated, orthoclase is proportionally large in its size, and usually encloses a more or less idiomorphic plagioclase; but I have never met with the reverse case. Prof. Rosenbusch repeatedly asserts most definitely, in his *Mikroskopische Physiographie, that the dogma, that orthoclase falls more easily a victim to decompositions than the other feldspars, is not based on ascertained fact*; but I generally find orthoclases to be more dirty, crooked, and fissured, and much more decomposed than the other members of the same group, when viewed side by side in the same portion of a slice. The monoclinic feldspar is fissured in all directions, and is also characterized by the presence of abundant liquid-inclusions and other foreign interpositions, especially when compared with the other feldspars. Well-defined crystals of a brown mica, indeterminable, colourless needles looking like sillimanite, crystalloids of hornblende,

[1] Dr. Dathe, when speaking of the order of crystallization of feldspars in the biotite-gneiss of the Eulengebirge, says:.....*scheint nach meinen Beobachtungen an diesen und zahlreichen anderen Gneissen und Granuliten der Plagioklas zuerst, hierauf Mikroklin, schliesslich Mikroperthit und Orthoklas sich ausgeschieden zu haben.* Jahrb. d. königl. preuss. geol. Landesanstalt für 1888. p. 318. Whether the same rule may or may not be applied to an undoubtedly irruptive granite like ours, is a question for the future.

zonally constructed zircon, red iron-glance, opaque iron ores, and lastly, apatite, are the usual guests. A bluish schiller, so common in the Swedish granites, is not observed.

In the advanced stage of decomposition, the mineral resolves itself into pseudophitic scales, whose tufts and aggregates are arranged at right angles, and also parallel, to the c-axis. The epidotization seems here to have not taken place; but if it does occur amidst the feldspar-substance, then the material for its formation must have been surely derived from the hornblende, evidence in favour of this being easily deduced from the presence of ropy strings of chloritic matter directly connected with the degenerating amphibole, and penetrated and infiltrated in the feldspar along the clefts in the latter. The polarization-colour is languid and dull, ranging from yellowish-brown to grey; a prominent feature is, however, the presence of the parallel-fibrous structure in crystals in a somewhat advanced stage of decomposition.

The *microcline* is present only in small quantities. Macroscopically, it can not be distinguished from orthoclase, as their colours and lustres are quite similar. Under the microscope the microcline nature can only be recognized by its characteristic reticulated or cross-hatching structure. The mineral is usually of a small, irregular form, filling the interstices of other components, and also forming the outer zone of the plagioclase or orthoclase. It is generally fresh, and pellucid, and is poor in liquid-inclusions; consequently it can not be supposed to have been produced by the albitization of orthoclase, like that of granite in Socotra.[1] It belongs to the latest generation. At times larger grains seem to occur in the rock-mass, and these are partly changed into muscovite. Small microcline forms, together with grains of quartz, a part of the rock, producing thereby what is called the

1 A Sauer, Zeitschr. d. deutschen geol. Gesellschaft, vol. XL. p. 146.

mortar structure, or with the same, a micropegmatic intergrowth; the latter is developed on the peripheral zones of other feldspars, and the stalks of quartz, which are disposed in regular orders, stand at right angles to the faces of the enclosed mineral.

The *plagioclase* occurs in the fresh state. Muscovite is always the mineral formed from it when weathered; no epidote crystal is ever found, a fact which speaks in favour of the acid character of the feldspar, of its being poor in lime. The quantity of the plagioclase is greater than that of the orthoclase and microcline. The plagioclase is usually of a large size, and with quartz it forms a part of the micropegmatic intergrowth. The twinning lamellation is distinctly developed, yet not so finely as in that of the labradorite series. Well-outlined clinopinacoids are seldom met with, as is usually the case in such granular rocks as granites, and the direction of extinction could be very rarely measured on that face; some opportunities were, however, afforded for such an observation, and it then extinguished light in the positive sense at about 8° with the edge P/M. Sections with twinning lamellations make an extinction-angle of 4° symmetrically with reference to the trace of the twinning sutures. From this it may be inferred that the plagioclase in question is of an oligoclastic nature, or else is closely allied to oligoclase, perhaps albite. A feature which characterizes this variety of feldspar is its zonal structure, and the presence of this feldspar could be readily recognized by the zoning, even without examining for the existence of the polysynthetic twinning. The plagioclase is rich in crystalloids of hornblende, lamellæ of biotite, round-edged needles of apatite, and nearly ellipsoidal crystals of zircon.

The *quartz* occurs, as is usually the case in granites, in a xenomorphic, angular form. Macroscopically it seems not to have taken an important part in the composition of the rock, and in some varieties it sinks into so small a quantity as to give to the specimen the appearance

of a dioritic syenite. The colour of the quartz is light-grey, and when it contains abundance of liquid-inclusions, and also stiff, bent, and broken trichites, it becomes more or less bluish in shade. These trichitic bodies come indifferently in quartzes of the granite-mass, and in the veinlets which variously traverse the quartz.

Notwithstanding the scarcity of macroscopic quartz, it is largely represented microscopically in the rock, and forms, with microcline or plagioclase, a fine aggregate between the larger individuals of feldspar, hence the mortar-structure of Törnebohm. Under polarized light between crossed Nicols, the variously coloured mosaics consist partly of the intergrowth of quartz and feldspar, radially arranged around the feldspar individuals, forming a sort of delicate fringe, and bringing about, in consequence, the pegmatophyritic[1] structure. The latter is chiefly confined to the fine-grained variety, containing richly zoned feldspar, but having only a small quantity of quartz-grains. The liquid-inclusions are abundantly present, forming band-like swarms, and the quartz containing them resembles a smoky quartz. Hexagonal scales of biotite and rounded crystals of zircon are also found as enclosures. Undulatory extinctions and optically diverse orientation of the grains show the rock to have been subjected to great pressure. It is remarkable to observe that where quartz is plentiful, striated feldspars with the cross-hatching structure are very abundant.

Accessory components are apatite, zircon, and iron ores including magnetite, titanic iron, and pyrites.

The *apatite* occurs as enclosures, especially in biotite and hornblende, and also as an independent ingredient. In the normal mass of granite it is comparatively rare, but in the caught-up granite, as well as in those of the contact cheeks of lamprophyres, tufts of apatite-needles

1 Lossen, *Vergleichende Studien ueber die Gesteine des Spiemonts und des Bosenbergs bei St. Wendel u. verwandte Eruptivtypen aus der Zeit des Rothliegenden.* Jahrb. d. königl. preuss. geol. Landesanstalt für 1889. p. 270.

pierce through the substance of hornblende and biotite, and particularly into the grains of feldspar enclosed by the hornblende of the caught-up granite. The larger apatite-crystals are short and broad, and have the edges rounded perhaps by corrosive action; the delicate, slender needles of the same mineral are sharply bounded by plane surfaces with, however, broken terminations, and are comparatively small in size. At first sight, both modifications seem not to be of identical chemical composition ; but their respective cross-sections give the clue to their true nature, and show that both modifications belong to the same mineral. The well-defined needles may be of a later origin, and their formation may be ascribed to the effect of a contact metamorphism.

The *magnetite* is sparingly present in the normal rocks, but in the schistose variety and also in the patches caught up by biotite-granite, it is plentiful, occurring either in a drop-like form, or in well-finished octahedrons. *Iron pyrites* forms part of clumps of magnetite, and performs the function of the interstitial mass between the granitic components, just like the mesostasis of younger eruptives. The octahedrons of magnetite are specially abundant within somewhat decomposed feldspars. Also in a partly altered hornblende, the same mineral fills up the clefts of cleavage-planes, appearing just like numerous black needles, all regularly arranged parallel with the principal axis of the crystal. As a whole, the formation of the magnetite seems to stand in intimate connection with the act of metamorphism. The deposit of magnetite in the valley of Chūka makes its appearance between the diatrophic clefts of a strongly compressed gneissose or schistose hornblende-granite, and the source of the iron ore must be sought for as similar to that of the formation of magnetite in the granite, already referred to. Sometimes blood-red tablets of iron-glance are interposed in feldspars with a certain definite arrangement, appearing in black needles and in minute red scales, producing thereby the

so-called 'aventurine lustre. The other iron ore, *titanic iron*, seems to occur in the rock, since its presence is indicated by the formation of leucoxene borders around the cores of iron. *Zircon* in grains and also in crystals of the usual habitus is chiefly enclosed in the hornblende and biotite.

Sphene is only observed in the hornblende-granite from Nakatani, near Ishikawa. *Fluorite*, so common in granites, is wanting.

The *coloured components* are represented by biotite, as well as by hornblende, and form the characteristic, dark, confusedly fibrous parts and flecks in the gneissose variety of the granites. In the striped granite the mica and hornblende have the same orientation, and the base of the biotite and the c-axis of the hornblende lie in the same plane. Consequently the maximum-extinction happens simultaneously in the two minerals, along the plane of the pressure-cleavage of the rock. Apatite, zircon, and magnetite are found as enclosures in the mica, while the hornblende contains besides them crystals of biotite, showing that the latter is of earlier generation than the former. The usual chloritic material, resulting from the decomposition of hornblende is absent in the cases hitherto observed. The amphibole is remarkably fresh. The biotite is, however, partially altered into green lamellæ by the bleaching of that mineral, these changed bands being interlaced with the fresh foliæ of the biotite; and the secondary epidote is also found in the bleached parts.

The *biotite* is by far the most common of the two minerals; the absolute quantity of it may, however, fluctuate within wide range. The pleochroic halos usually so common in it are discerned here only in a few cases. Observed from the base, it is of a dark-brown shade, and sometimes so intensely coloured as to give the appearance of an opaque body. It may at once be conjectured that the mineral is highly ferriferous, and the result of an analysis made by Mr. Hida, of the

Geological Survey, establishes its chemical nature to be that of *lepidomelane*. The following percentages are those found by him:—

SiO_2	36. 60
Al_2O_3	17. 05
FeO	21. 29
CaO	trace
MgO	10. 36
Mn_3O_4	0. 70
Na_2O	5. 39
K_2O	8. 49
	99. 88

The angle of the optic axis is so small as to give almost an uniaxial stauroscopic figure.

The hornblende-granite occurs very frequently in detached masses and in lenticular forms, enclosed within biotite-granite of a more acid composition and of a much later origin. The biotite in such a *caught-up granite* presents a peculiar feature not observed in the normal mineral. The mica is here devoid of its crystallographic outlines, and the deep brown lamellæ of this mineral with different optical orientations are heaped together around the larger one. Thus the microscopic scales of the biotite with its marginal ragged structure possess the same habitus as those found universally in contact rocks, and in many of the crystalline schists. The larger crystals are interlarded with needles of apatite.

The *hornblende* has a bluish-green colour. The extinction-direction varies within wide latitudes, and gives usually larger angles than those of common species. The most distinctive feature of the hornblende of our granite is, however, its weak pleochroism, comparatively faint polarization-colours, contrary to our expectation from its deep bottle-green colour. The degree of absorption is normal : $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

The habitus of the crystals of hornblende is to be slender, flat, and prismatic, with the faces oP, $\infty P\bar{\infty}$, $P.\infty P\bar{\infty}$, and ∞P: twins are rare (Fig. 2, Plate XXIII.) The analytical result obtained by Mr. Hida is as follows:—

SiO_2	45. 61
Al_2O_3	4. 47
FeO	8. 92
CaO	26. 40
MgO	11. 44
Na_2O	2. 26
K_2O	0. 79
	99. 89

The hornblende in the *caught-up* granite, like the biotite, shows some peculiar marks entirely foreign to the common species. In the massive granite the crystals of hornblende are usually idiomorphic, while in the caught-up rock they are of large dimensions and at the same time allotriomorphic, playing just the same role as the augite in diabases in the formation of the so-called diabasic structure. In the normal sequence, as is well known from the observation of Prof. Rosenbusch, the crystallizing-out of the ferro-magnesian bisilicates precedes that of the feldspar-group. Here we have some exceptional cases, probably arising from the uncommon circumstances under which the rock reached the solid state. A somewhat large, allotriomorphic hornblende of a dark-green colour, encloses, as it were, the interstitial mass of basaltic rock, a number of equally allotriomorphic crystals of plagioclase oriented in diverse directions (Fig. 7, Plate XXIII.). The plagioclase (? albite) in the present case presents the habitus of albite with corroded appearance, occurring usually in large quantities in the schistose amphibole rocks. The hornblende occurs in the form of an ophitic plate with uniform extinction over

considerable areas, just as the augite behaves within the mass of diabasic components. This ophitic plate of hornblende is well exemplified in the rock from Kawa-na, near the railway station at Iwanuma. The hornblende, like the biotite occurring associated with the amphibole, is variously pierced through by needles of apatite.

The granite-hornblende immediately in contact with the dyke of lamprophyre presents quite an anomalous feature, one deviating from the habitus hitherto described, the changes in it having been, beyond all doubt, brought about by metamorphism in coming in contact with the intruding dyke. Here the amphibole is smaller in size than the other variety, and moreover, occurs in rather flat prisms more bluish than green in colour, while its cleavage-sutures are numerous and distinct. Its crystals show diverse intergrowth among themselves, a phenomenon rarely observed in other cases; the outlines of larger individuals are irregular and allotriomorphic. In short, the whole appearance is an exact copy of that commonly met with in some granular crystalline schists.

Among the secondary minerals may be mentioned *epidote* in somewhat large grains with its customary intense pleochroism: it is found usually enclosed within a more or less bleached biotite or in hornblende.

The material for the formation of epidote must have been directly derived from the enclosing minerals. Feldspars, though showing an advanced stage of decomposition, are free from it, indicating that the feldspars in the present case are poor in lime. When epidote occurs, it can only be that the material for it has flowed to that spot by capillary action through the cleavage-plane, or through some fissure admitting free passage. The epidote-grains thus originated are connected by strings of chloritic materials to the mother-mineral, which is, as is already stated, either biotite or hornblende. The

end-product of decomposition of the last two minerals, the hornblende and biotite, are chloritic substances, while feldspars end in producing a pseudophitic mineral, which is regularly arranged with reference to the crystallographic outlines of the original mineral. This is rendered visible in the aggregate colours of polarization by the peculiar position of foliæ of a muscovite-looking mineral.

B. Structural varieties of Granites.

a) Amphibole-Granite.

The principal rock of the Abukuma plateau, the amphibole-granite, shows a great uniformity in its mineralogical composition, but varies locally in texture with the relative proportions of the composing minerals. It consists essentially of quartz, orthoclase, plagioclase, microcline, hornblende, and biotite, the last two ingredients being present nearly in equal quantities. As all granites contain some quantities of micas, I suggest for the present rock the name hornblende-granite. The accessories are apatite, zircon, and iron ores; titanite is rare. The general colour is rather greyish; but the weathered rock is of a rosy tint, owing to the oxidation of iron in the feldspars, and may be distinguished as the pink-granite.[1]

For the type of this amphibole-granite may be taken that from Gomi-sawa, in the Jigoku-road, 1½ ri south-east of Ono-shin-machi. It is coarse crystalline, and its crystals of hornblende attain a length of more than 1 cm. The deep oily-brown biotite is entirely or partially enclosed by the amphibole; consequently the former precedes the latter in the act of crystallization. The pellucid needles of apatite accumulate at the margin of these coloured minerals. Plagioclase, with a rather coarse twinning-lamellation, is idiomorphic in

[1] See *ante* p. 220.

comparison with orthoclase, and is usually enclosed by the latter. The twinning lamellæ extinguish light at small angles, consequently it may be fairly supposed that the mineral belongs to the oligoclase-andesine series. The broad zoning is distinct, with differentiated extinction-angles. The orthoclase is angular and allotriomorphic, its apparent regular outlines having resulted from the disposition of the adjacent crystals, especially of plagioclase. Quartz fills up the interstitial spaces left by other minerals, contains crystalloids of feldspars, and appears somewhat fibrillated, especially when viewed by polarized light between crossed Nicols. The quartz is comparatively free from liquid inclusions.

As to the structure I have to say only a few words. One of the most interesting features of our granite is the presence of the allotriomorphic feldspar, playing just the same rôle as the granite-quartz; that is to say, the interstitial masses of a non-striated feldspar between a more or less well-finished plagioclase. These masses show a homogeneous extinction over a wide area, like the vitreous base of many neovolcanic rocks; and though occurring in detached spaces, they possess surely an optical continuity. Where this kind of feldspar comes in direct contact with equally allotriomorphic quartz, the boundary is an irregular one, and the two must be supposed to be synchronous productions in the act of crystallization of the rock. To what class of feldspar it may belong is very difficult to decide. It looks like adularia and fresh, while the enclosed plagioclase exhibits more or less an advanced stage of decomposition. Notwithstanding the fresh appearance of the feldspar, it displays only weak polarization-colours, by which the other feldspars and quartz are readily distinguished. Through the want of crystallographic outlines there is no means of getting any optical proof. Lately,

[1] Zeitschr. f. Krystallographie. 1890, XVIII, p. 192

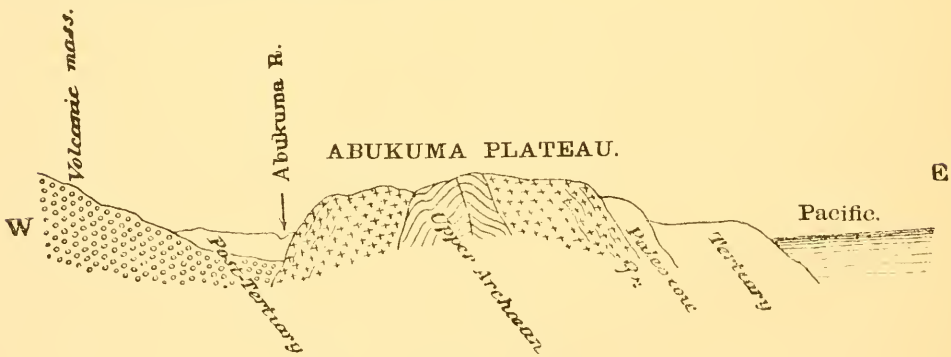
Dr. A. Sauer and Dr. N. V. Ussing, while studying the minerals of a pegmatite dyke, have found out, that the microcline occurs in simple crystals, or in twins of the Baveno type, exactly like an orthoclase-crystal; and that characteristic, cross-hatching structure, by which alone the microcline-nature is usually recognized under the microscope, is not always fully developed. The true nature of it has been placed by both authors beyond all doubt by an exact chemical analysis, and by optical investigations on the well-oriented preparations. Therefore our feldspar, which is also not doubly twinned, may perhaps be looked upon as a variety of microcline.

The granite hitherto described forms a wild creek along the deep ravine of the Natsui-gawa, which runs at its lower course by the populous town of Taira. Recently a new road was opened toward Miharu, and the traffic thereby very much facilitated; but just a few years ago, it was one of the worst roads of this region; hence the name of the Jigoku-dōri, or the Devil's way. New road-cuttings now give good exposures of the granite.

At various localities the hornblende-granite forms a gradual transition to the so-called *granite-gneiss* or *gneiss-granite*, and we can trace them step by step from one extreme to the other, without finding any abrupt discontinuity. There are, however, other *gneisses* occurring in the same region, which look, at first sight, like schistose varieties of the preceding granite; but in truth the former has nothing in common with the latter, in regard to its genesis. The genuine gneisses, already referred to, are true members of the archæan group, perhaps the lowest and therefore the oldest rocks which we shall ever be able to find in the edifice of the Japanese islands. Confusion of the genuine gneisses with the apparent ones has thrown many of us into an intricate labyrinth, from which

hitherto none could find the way of escape. The present writer endeavours to decipher, in subsequent pages, the complicated mode of arrangement of these ancient complexes, and the stratigraphical order of the schists of which the archæan is composed.

The *schistose variety*—the gneissose granite—,occurring in connection with the hornblende-granite, and forming a part of one and the same mass, is only a dynamo-metamorphic facies, but brought about under special conditions. The stowings, foldings, and faultings of the masses of rocks, so common during a mountain-building, have occurred in the Abukuma plateau only at the marginal zones; while the portion, of which the central height is formed, has remained quite intact. There has been produced a differential movement, leaving the interior as a standing block, called geologically the *Horst*, the east and west sides of the plateau being thrown down to a lower level, along the meridional dislocation-lines.



Ideal profile of the Abukuma plateau.

I had frequent occasions to observe, during my short visit, occurrences of the schistose variety (gn) along the Pacific coast, and also along the Abukuma-gawa, while the height lying between them is occupied by a normal, typically granular granite. I shall come again to the same subject, when speaking of the geotectonic condition.

It may not be out of place to speak shortly about the nomenclature. It has now become almost an imperative duty for petrologists to separate sharply the *granites* from the *gneisses*. Prof. Cohen[1] long ago pointed out that by gneiss we understand a genuine stratiform rock; and into such a rock granite is never transformed, however perfectly the latter may show the schistose structure. Such rock is properly to be designated schistose granite. As granites and gneisses are geological bodies genetically quite different, so ambiguous names like granite-gneiss and gneiss-granite, given to the metamorphosed rocks, had better be totally expelled for ever from petrographical literature. I follow the good example of Prof. Cohen, and call hereafter such dynamo-metamorphic products *schistose granites*. In order to avoid confusion, this is fundamentally necessary for a country like Japan, where these schistose rocks are so largely developed, occurring side by side with genuine gneiss, as for example, in the southern part of the Mutsu chain, in the mountains of Abukuma, Akaishi, Suzuka, Kasagi, and Katsura, as well as in the northern part of the South-Kiūshū range[2]. I now return to the granite, namely:

b) Imperfectly Schistose Amphibole-Granite.

As has been already pointed out, the transition to this is very gradual, and there arises consequently a number of intermediate forms, which do not allow of brief characterization. As we approach the *schistose granite* from a region of *normal rock*, it is hardly perceptible where one begins and the other ends. On large exposures such transitional rocks may be best seen by their peculiar habitus, somewhat deviating from a normal structure. On the other hand, specimens

1 *Geognost. Beschr. d. Umgegend von Heidelberg*, 1881; see also *Ueber das krystallinische Grundgebirge der Insel Bornholm*.

2 T. Harada, *Die Japanischen Inseln*, Tōkyō, 1890, p. 46.

taken from such a spot give scarcely a clue as to their true nature, especially by examining them on a fractured surface, corresponding to the plane of schistosity ; but on a face broken across that plane, the black components show a faint indication of arrangement in a definite plane. In small chips, even this structure can not be discerned.

Under the microscope with thin preparations, however, many proofs of its being affected by a mechanical deformation become evident. First of all, the uninjured *quartz-grains* already show a so-called undulatory extinction ; diverse net-works of the bands of liquid-inclusions grow numerous ; and adjoining faces of quartzes among themselves get more and more irregular, displaying vivid mosaic colours under polarized light between crossed Nicols, but not so the faces adjacent to other components. The innate but latent twinning lamellation of *feldspars* becomes visible by this time through the mass-motion of mountains. The feldspars polarize in brilliant colours, and show also undulatory extinctions akin to the connate quartz. *Biotite* in normal granite has usually a regular outline, but in this transitional rock the original form is now more or less obliterated, showing wavy bands, and its characteristic nacreous lustre between crossed Nicols. The biotite is loosened and fibrillated on the side in direct contact with the feldspars, and the latter specially kaolinize at the adjacent portion of the mica. Consequently, the cause of alteration both of feldspars and mica is *not merely atmospheric, but must be ascribed to some inner movement of the rock.* It is particularly noticeable to find frequently the secondary epidote (Fig. 4, XXIII). in conjunction with degeneration of both minerals, and the substratum necessary for the formation of epidote may probably have been contributed by biotite and feldspars, just as in the case of other *reactionary minerals.* The usual alternation of the green, bleached bands with the fresh lamellæ of biotite makes here its

appearance. Fine, microscopic, trichitic needles are abundant in the quartz. *The first inducement to the schistosity of our granite is to be found in a slight shifting in the position of the ferro-magnesian silicates, and also in the commencement of granulation in the solid quartz.*

In the rock forming a cheek of the deposit of magnetite in the Chūka valley, which may conveniently be classed among the present group. I found many patches of the *micropegmatite*, filling up the interstitial spaces between the constituent minerals. Feldspars are beautifully zoned, and polysynthetically twinned; their peripheral portion is astonishingly irregular, gradually fusing together with the feldspar-substance of the micropegmatite. The feldspar forming the marginal portion, above mentioned, has the appearance being formed by the secondary enlargement, repeatedly spoken of, of late, by many American and English authors. It is a subject of considerable interest to know whether the *pegmatite in question is of primary or secondary origin.*

Prof. Judd[1] recently advocated the view that the formation of pegmatites and granophyres[2] may take place after the consolidation of rocks by the way of devitrification, concentration, and differentiation of a substance similar to glass-base, if there be any in granites, that is to say, that they are not original but secondary products. I found the true pegmatitic structure in some of our schistose granites as, for example, in the specimen from Chūka, a rock changed in its texture by pressure. This fact seems to have some important bearing on the view of Professor Judd, just stated. But I have also found the same in some normal granites, which have not been even slightly affected by dynamic changes. *Under these circumstances no decision can*

1 Q. J. G. S. Vol. LXV, 1889, p. 179.

2 Professor Lossen wishes to substitute the word *pegmatophyre* for the granophyre of Rosenbusch. *loc. cit.* p. 270.

be made as to the origin of the pegmatitic structure being primary or secondary.

c) Schistose Amphibole-Granite.

This modification may be readily recognized as such even on a cursory examination of hand-specimens, and no confounding with the normal granite is likely to occur. It is of a coarse, granulo-lamellar *(flaserig)* structure, and generally of a rather darker shade than the primary rock. The schistosity is imperfectly developed; consequently the cleaved surface is exceedingly rough, irregular, and notched. A typical rock belonging to this class is well exposed along the steep ascent of the Kawachi tōgé (Kawachi pass), between the town of Tomioka and the village of Kawachi, and is also found near to the iron deposit of Chūka, Naraha gōri. This is really what Mr. Kochibe calls the "*Iwaki gneiss.*" All microscopically visible components are now crushed into deformed bodies; the hitherto even-lamellar biotite is altered into flexuous and wrinkled lamellæ; the hornblende is no longer of a prismatic form; the quartz and hornblende are rolled out and grained, and compacted into one mass with *a feldspar centre zoned by the grains of quartz*, well seen on a weathered surface on account of the different degrees of pellucidity of the two minerals.

Examining with the microscope, the structure becomes more apparent. Originally fresh minerals have acquired a dirty aspect and become variously fissured. In the first place the biotite is for the most part bleached, and its chloritic bands are interposed between light-brown lamellæ. No trace of its original outlines is preserved. A chloritic, fibrous substance often creeps along the adjoining faces and fissures of the compact biotite, and the fibrous mass is connected by strings from the mother-mineral, either hornblende or biotite. The hornblende has met the same fate; its margins are irregular and frayed,

surrounded by accumulations of the epidote grains; the peripheral portions are chloritized, leaving cores of the hornblende in the centre. The secondary epidote occurs fringed with chloritic fibres, and this general distribution of the green minerals causes the rocks to appear of a dark-green shade. The large well-defined crystals of magnetite are newly formed; the small crystals of it are heaped together in the spot formerly occupied by the magnesium-bisilicates out of which they have been formed. The leucoxene mineral encircles the rounded magnetite, from which it may be inferred that the iron ore is titaniferous. The quartz is darkened and clouded with an immense accumulation of liquid-inclusions, arranged in bands along the fissures and cracks.

As to the feldspar it is for the greater part kaolinized, especially in the central portion; the periphery remains comparatively in an unaltered condition; the original shell-structure and the chemical difference in the zoning thus become apparent; the peripheral portions of the crystals display weak polarization-colours. Some feldspars appear homogeneous by simple transmitted light; but after applying crossed Nicols, twinning structures are well exhibited by different colours in alternate lamellæ; and, moreover, extremely fine lines are developed just across the twins of the first type. These second twins do not extend over the whole breadth of the lamellæ, but are usually only partial, being very abundant along the twinning plane of the albite type. The feldspar, apparently of an orthoclase nature, is, therefore, really microcline, having the characteristic cross-hatching structure. Where feldspars come in direct contact with the chloritized biotite, a zone of accumulation of epidote grains occurs in the substance of the feldspar, around the altered biotite, in such abundant quantity as to make that portion appear quite dull. The feldspar itself appears at first sight simple and homogeneous, but when viewed by polarized

light it shows undulatory extinctions. Moreover, the whole substance is composed of fine grains which are only made visible by the difference of the optical orientation of the several fragments. Between the epidote zone and the biotite the space is still occupied by a feldspar, but besides this, needles of epidote shoot across from the granular zones into the substance of chloritic fibres (Fig. 4, Pl. XXIII). *The formation of the secondary epidote is due evidently to the reaction of biotite and feldspar.*

As to the state of aggregation of the individual components, I have to add only a few remarks. I have already spoken about the structure of the *imperfectly schistose granite*, which is mainly due to a slight shifting of the coloured components, and this fact may be readily made out from the deformation of their crystallographic outlines. In the present case the schistose structure is more perfectly developed than the one just referred to, and is distinctly fibrous-lamellar, resembling somewhat the structure known as the "eye"-gneiss.

Under the microscope the hornblende and biotite are seen to be not only flattened and compressed, but the entire crystals were materially altered into chloritic fibres, leaving here and there only cores of hornblende and scanty remains of lamellæ of mica. Sometimes the decomposition has gone so far that a few epidote grains alone indicate the spot which both minerals once occupied, but nothing of their substance can now be seen. More than this, the allotriomorphic quartz, filling up the space left vacant by other components, is for the most part crushed, presenting a mosaic by polarized light. Simultaneously with this granulation, the quartz fragments have been shifted one over the other, penetrating into wedge-shaped interstices wherever they have been allowed to do so. The feldspar is the most obstinate of all the components, standing solidly in its original position, while other ingredients have partaken of the general decompositions and migra-

tions. This being the case, *the feldspar has become encircled by quartz*,[1] and this, as I have already stated, may distinctly be seen in hand-specimens even with the unaided eye, although the substance of the feldspar has evidently suffered great contortion, as may be inferred from the bending of the polysynthetic lamellæ.

The untwinned, simple feldspar, a product of the second generation of the same mineral, has a habitus akin to that of the granitic quartz, having filled up the spaces between the lamellated plagioclase, hornblende, and biotite, and consequently imbedding the above-mentioned minerals. It is highly probable that the *ophitic feldspar*, if I may be allowed to use this expression by analogy with the ophitic augite in diabases, is monosymmetric; for, no polysynthetic twinnings have heretofore been observed in it. This feldspar is a far later product of crystallization of the granitic magma, but its formation took place slightly earlier or almost cotemporaneously with that of quartz, although no micropegmatitic structure has been produced. The boundary between the later feldspar and the quartz is the most irregular possible, indicating that they have consolidated not far from each other in the order of crystallization. The later feldspar has not suffered granulation, the quartz, on the contrary, has been reduced to a mosaic mixture.

d) Schistose Epidote-Granite.

In macroscopic appearance it differs from the preceding by its dark shade, owing to the general distribution through it of chloritic matters, and also to the presence of green patches of epidote. Its structure is granulo-lamellar, nearly approaching that of the plane-

1 This peculiar structure seems by no means to be of rare occurrence. Mr. Teall, while speaking of the granite from St. Davids, which has given rise to a good deal of discussion, incidentally makes the following statements: *The relation of the quartz to the feldspar in this rock is interesting. Sometimes the two minerals occur in irregular grains, at other times the feldspar plays the rôle of matrix to the quartz,... British Petrography*, p. 318.

schistose modification ; transverse sections of the rock have a banded appearance through alternation of feldspar-quartz zones with those impregnated with chloritic matters.

Under the microscope, the coloured components—the hornblende and biotite—are seen completely crushed and fashioned into flat spindles, and these resolved into green fibres, but some have cores unchanged. Sometimes the hornblende has disappeared entirely, being replaced by masses of epidote and magnetite. The biotite is bent, and frayed out at the margins. Heterogeneous aggregates, consisting of grains of epidote and clumps of magnetite, together with chloritic matters, form sinuating zones, contracting and widening at short distances. *The feldspar, the most enduring mineral, has escaped the general destruction and granulation, excepting its peripheral portion, where the texture is loosened and crushed, producing the cataclastic structure, and there the chloritic fibres have settled, lining the borders of the feldspar. In spite of the solidity of quartz, this was the first that yielded to pressure, and its crushing already seen in the (b) imperfectly schistose granite, is still more evident in the (c) schistose granite.*

Lastly, in the schistose epidote-granite the quartz is totally reduced to fine dust. Examined by transmitted light, the quartz appears like a homogeneous, colourless base, encircling and flowing around a somewhat porphyritic feldspar. Fine dust is distributed throughout the white mass, and the mass of quartz looks rough, as if it were, the sliced face of a mineral, like olivine. With crossed Nicols the masses resolve themselves into a truly mosaic aggregate, one grain lapping over the other, and flowing along round the deformed edges of the feldspar fragments. The usually vivid colours of polarization, are now faint-blue, and the extinction of light sweeps over from one part to the other

c) Biotite-Granite.

This is coarse and granular and of a lighter shade, being made up of a flesh-red orthoclase, quartz, and a little biotite. Under the microscope some muscovite may be seen, *while this mineral is entirely wanting in the hornblende-granite, already described.* The lath-shaped feldspar with twinning lamellation extinguishes at small angles symmetrically with the twinning sutures, consequently this plagioclase should be classed among the oligoclase series as in the other granites. It is idiomorphic in comparison with the orthoclase, which usually encloses it, and consequently the lamellated one must be the older. The orthoclose is more or less kaolinized, and its crystals are usually twinned on the Baveno type. The quartz has the same habitus as that in the hornblende granites, and is poor in liquid-inclusions. The biotite is common ; zircon and the blood-red iron glance are found as accessories. The rock occurs in good exposures at Kawa-uchi, Naraha gōri.

The most interesting fact in connection with this granite of the Abukuma plateau is the occurrence of *black patches of the hornblende-granite caught up and enclosed by the light-coloured biotite-granite.* The enclosed granite is really the fragments with sharp angular edges, torn off with great force from a mass of completely consolidated rock of older date. The size of the fragments varies from 5 to 15 cm. New road-cuttings and the bottom of rivulets expose the structure in full detail. Looked at from a distance, the rock appears like a coarse conglomerate or breccia, or a mass stained with gross marks upon a white ground. It is indeed a breccia of effusive origin and primary, the older black granite, *bearing the hornblende*, being cemented with a matrix of the younger *biotite*-granite, the latter differing from the first only in the different development of ferro-magnesian silicate. The granite enclosing the older fragments is wide-spread in the region

of the western brim of the Abukuma plateau. Commencing from Miharu, and extending northwards, the outskirts of this region may be found on the left side of the Abukuma-gawa near Nihon-matsu.

Examining this rock more closely with high powers, many interesting facts are unfolded by the microscope. The boundary between the two granites is sharp and abrupt; the enclosed rock is violently broken at its margin and terminates with keen edges, forming here and there coves and inlets within the confused mass, where the intruding or younger granite has pushed its material through any free space.

The intruding granite.—The younger granitic portion is quartzose at the junction, consequently it rarely happens that its components other than quartz come in direct contact with those of the enclosed rock (Fig. 1,[1] Pl. XXIII). The quartz is here variously fissured and broken, and the lines of fracture thus produced run approximately parallel with each other, their prevailing course being directed against the extended margin of the enclosed rock. The quartzes at the junction are dotted with swarms of liquid-inclusions which increase in number as they approach the meeting points. It is usual among contact phenomena to observe the development of air and gas inclusions, which, contrary to our expectation, is not the case in the present rock. The feldspars rarely happen to meet directly with the components of the enclosed granite. Where they do the feldspars are not homogeneous, and intact; the substance of the crystals is crowded with patches of a colourless mineral, and consequently the whole aspect simulates the appearance of either andalusite or staurolite with rich interpositions of quartz. Some of these interpositions of the feldspars may be of a negative character, made hollow by some etching solvent along the plane of chemical weakness;

1 The lower half represents the intruding, young (biotite-) granite, the upper half the intruded, older (hornblende-) granite.

others again are real enclosures of either quartz or feldspar with other optical orientation than the main mass, while the third are rather larger patches of another kind of feldspar with systems of twinning striations nearly at right angles to those of the enclosing minerals. The last have a close similarity to that of the albitized orthoclase of the Socotra granite, as described and figured by Dr. Sauer,[1] from which, however, they differ only in one particular that the changes which the mineral has undergone are not in orthoclase, but in the substance of a striated feldspar. The orthoclase is comparatively free from these patches of plagioclase, but full of irregular cracks. The quartz outweighs the striated and the non-striated feldspars, therefore this rock must be of highly acid composition. Minute crystals of apatite are abundant in quartz near the margin of biotite, being often dismembered and crooked ; the pleochroic halos are observed in biotite ; globular grains of magnetite are scattered through the general mass. Zircon is also found in fine crystals in the combination of the faces of ∞ P, and ∞ P∞, with indistinct terminations.

The enclosed granitic patches.—The plagioclase is idiomorphic with respect to that of the biotite-granite, and at the same time zonings are beautifully developed in it, which are not found in that of normal hornblende-granite. At times its central portion is more or less decomposed, and crystalloids of a bottle-green hornblende are scattered throughout that area (Fig. 7, Pl. XXIII). The feldspar is on the other hand fresh and intact in its outer, and the hornblendes within the core were probably formed by contact metamorphism. Epidote-grains of a tolerably large size occur enclosed in an apparently unchanged feldspar. The epidote seems to be wanting in the biotite-granite (intruding granite). Striated and non-striated feldspars occur in equal quantities, but their distribution in the rock-mass is not

1 Zeitschr. d. deutschen. geol. Gesellschaft, Vol. XL, p. 146.

uniform. As a general rule they are in fine crystals. The same globular interpositions, already spoken of, make their appearance in these feldspars as in those of the intruding rock, and the quartz penetrates into the substance of the feldspars, just like the pockets in the quartz of quartz-porphyries. The hornblende forms the most important of all the components not only in respect of its quantity, but of its very occurrence in the rock; while in the enclosing granite we fail to find even a trace of this mineral.

This fact affords us a clue to the two granites being of totally different origin, and by no means mere bands, such as might arise from local differentiation and partial movement of a granitic magma. Moreover, the angular and broken outlines of fragments of the rock speak for the foreign origin of the hornblende-granite; and the presence of the amphibole in this and the absence in the other give conclusive evidence as to the really fragmentary nature of the older granite caught up by the younger one.

The hornblende is dark bottle-green, and non-pleochroic, or, if at all, very weakly so. It is destitute of its own form, its apparently regular outline being due to the mutual dispositions of the neighbouring quartzes and feldspars. The mica is comparatively idiomorphic with respect to its closely associated hornblende, and grows round the hornblende in clusters. The biotite is often enclosed in the hornblende, consequently some of it must be younger than the mica. It is highly probable that the imperfectness of the shape of the hornblende is due to its simultaneous formation with the feldspars. The quartz is comparatively rare, and contains abundant liquid-inclusions. Titanite in the form of grains is also found which is wanting in the biotite-granite. Black iron-glance, reflecting somewhat bluish rays, is plentiful; some yellow pyrites is present. These iron ores have hitherto not been discerned in the biotite-granite itself.

VI. Petrography of the Takanuki Series.

A. Gneiss-Mica-Schists.

This occurs in a tabular form with the plane-parallel structure; the surface of a cleaved slab of this rock is entirely covered with aggregates of biotite, while its transverse section is striped with black on a yellowish-white ground. This peculiar appearance arises from the interbanded zones of black mica in the quartz-feldspar layers; the general colour is light-grey with a slight tinge of yellow, being caused by the pigment of the hydrous sesquioxide of iron that has infiltrated every fissure in the quartz and feldspar. Where biotite forms a component only in small quantities, this rock approaches both in appearance and composition to a granulite. Of course, such a granulite deviates in habitus from the typical one of the Mittelgebirge of Saxony, in having a rather coarse-granular texture, and also by the absence of the so-called microperthite. Weathered exposures of this rock look not unlike a disintegrating sandstone-mass.

The prevalent component is *quartz*, and the rock may fitly be termed a biotite-schist. The quartz abounds in liquid-inclusions with enclosed bubbles which on warming soon disappear from sight, indicating the presence of liquefied carbonic acid. These liquid-inclusions form chains, traversing different grains, irrespective of diverse crystallographic orientations, as is frequently mentioned in writings on crystalline schists. This phenomenon would be best studied in a slice, cut parallel to the plane of schistosity of a rock, brought from Shimo-Matsukawa, near the village of Takanuki. Contrary to my expectations, it was, however, not observed in a slice made at right angles to the former section, a fact indicating that the rock had yielded to pressure, in the direction parallel to the plane of schistosity, but not in that at right angles to it. In individual grains, liquid-inclusions are,

however, not wanting, and swarms of them crosss the rock vertically to its bedding.

The quartz contains, besides, as enclosures, almost colourless dodecahedrons of garnet, needles of zircon, and deep, reddish-brown flakes of biotite—all making the quartz, between crossed nicols, appear like a spongy mass. There are also fine, dark or brown needles, sometimes disjointed, shooting in various directions, similar to those of the quartz in tonalite, which are so frequently described, but whose nature is so little known. The quartz is, as usual, intensely chromatic, when viewed between crossed nicols; but not all the quartzes found in this rock behave in like manner. The one which has been already granulated, displays vivid chromatic colours; while those which are still under high tension show only a weak grey tinge, and at the same time undulatory extinctions which gradually sweep over the section one after another as is rotated. The crystallization of the silica must be of a comparatively recent date, as may be seen from a great number of pre-existing minerals contained in the substance of the quartz.

Still later in its crystallization, or nearly cotemporaneous with that of quartz is the *feldspar* which, as I have already stated, makes only a small fraction of the whole rock which not infrequently passes locally into a typical mica-schist. There are, however, other cases in which the rock makes transition in another direction, by taking up a large quantity of both monoclinic and triclinic feldspars in becoming a typical gneiss. Generally speaking, the distribution of the quartzose and feldspathic components in the rock are very fluctuating. One portion may be built up only of quartz, while the other will be highly feldspathic, so that in a coarse variety found near Daibara in Shimo-matsukawa, any one may name one portion of the rock a *mica-schist*, while the other may be reasonably taken for a typical *gneiss;*

but both modifications are really one and the same rock, and should not be interpreted as alternations of two.

The substance of the *orthoclase* is for the greater part kaolinized, and has a dirty aspect ; there is therefore no difficulty in discriminating it from the quartz grains, which are otherwise not very easy to distinguish, when both are found together unchanged. The feldspar appears *isometric-polygonal* in outlines, owing to the disposition of the biotite and quartz ; and patches of it, widely separated from each other, behave optically alike, showing that they are all one mineral, just as in the case of pegmatite. Its polarization-colours are weak, and zonings are frequently observed.

There occurs also *another feldspar* which deviates in habitus from the preceding in having a granular form, polysynthetic twinning lamellation, and comparatively high polarization-colours. This plagioclase is idiomorphic in comparison with the above-mentioned orthoclase, and appears less altered than it. The plagioclase as well as orthoclase often contains round grains of quartz,[1] around which the feldspars show more or less signs of decomposition. The angle of extinction of the plagioclase is small, making nearly 2° only with the sutures of twins, thus pointing out the andesine-oligoclastic nature of the present feldspar.

The *biotite* occurs in irregular foliæ, and is of a reddish-brown colour ; *rutile* disposed as in sagenite is found in great abundance ; the pleochroic halos seen around thick but short crystals of zircon may be frequently observed. Besides large lamellæ of biotite there occur minute scales of the same mineral. They are round or sometimes rudely six-sided, non-pleochroic lamellæ of microscopic dimensions with deep-reddish-brown colour. A spindle-shaped, lamellated, highly pleochroic crystal is only a side-view of the same mica. These

1 Kalkowsky, *Die Gneissformation des Eulengebirges.* p. 30.

microscopic bodies are mostly found imbedded in quartz. The primary *muscovite*, though subordinate in quantity to that of biotite, still forms a constant component. It is usually resolved into loose foliæ, and occurs often interlaced with bleached, green, fibrous biotite.

Accessory minerals are zircon, and a cherry-red garnet, which never occurs with crystallographic outlines, but usually in rather large grains, lapped and encircled by the lamellæ of biotite. It contains in it many brown scales of magnesia mica, gas-pores in the form of dodecadedra, and also colourless grains which are usually supposed to be of a quartzose nature. The garnet was observed microscopically in nearly all the slides examined; it may, therefore, be looked upon as a characteristic accessory component, and this fact makes some of the rocks of this group approach more closely to a genuine granulite.

Among the various modifications, the following are the principal types :— *gneiss-mica schist*, *two-mica schist*, *garnet-biotite schist*, and *hornblende-biotite schist*.

A *a) Gneiss-Mica-Schist.*

Scaly, light-grey, thick tabular schist with the plane-parallel structure, being made up of quartz, orthoclase, plagioclase, and biotite. The last mineral is arranged approximately in one plane, alternating with the quartz-feldspar aggregates. The four components are all nearly of the same size (1 mm.), and the weathered rock appears not unlike a micaceous sandstone. The quartz and feldspars are present in equal quantities, the former is often *partially or wholly enclosed by orthoclase*. The liquid-inclusions with the condensed carbonic acid and bubbles are abundant in the quartz, being disposed in chains ; other enclosures are round, tombac-brown biotite, clumps of the opaque iron-glance, and only a few grains and prisms of zircon.

The feldspars are of two kinds, the one orthoclastic, the other plagioclastic; the latter is minute in size, polysynthetically twinned with the angle of extinction of 3°-4° with the sutures of the fine lamellæ. The orthoclase exhibits dull-yellowish polarization-colours, and encloses often the twinned feldspar. *Both feldspars are remarkable on account of their enclosures of many quartz-grains with different optical orientations.*

The micas are also of two kinds; the tombac-brown biotite in ragged lamellæ without any crystallographic outline, with unusually dark pleochroic halos, including rutile-needles in the sagenitic form; the muscovite only in slight quantity, enclosing and often enclosed by the biotite. Accessories are zircon, apatite, and iron-glance.

The rock from Nishiyama, 1½ ri south from Takanuki, contains many stiff, disjointed needles of sillimanite (Fig. 9, Pl. XXIII); the one from the Nakayama pass, on the Nakayama road, from Tanagura to the province of Hitachi, contains a green, fibrous biotite together with white mica. *This rock is specially interesting in the possession of impressions like etched figures on the surface of the crystals of its feldspars, which are disposed one after another in series, parallel to the principal axis of the crystal.* Moreover, large crystals of ideally pure andalusite (3 mm.) are present irregular in outline, and encircled by confused aggregates of fibres of muscovite. A few of the crystals are coloured, and then are pleochroic, and rose-red when the principal axis of the crystal is parallel with the short diagonal of the polarizer. There are some traces of prismatic cleavage, which are made more distinct by the infiltration of the hydrous sesquioxide of iron.

A *b) Two-Mica-Schist.*

A typical specimen of this variety may be found in the cliff near Sōri, not far from Ishikawa. On a cursory glance it appears just like

a quartzite, being essentially made up of quartz grains together with thin layers of a brown biotite and silky mica. Under the microscope the schist is seen to be built up of quartz, biotite, feldspars in small quantity, and lastly, long, thin, lamellar, colourless crystals resolving at both ends into stiff fibres. The last-mentioned mineral is traversed by fissures at various points, and is not bent and lamellated like ordinary micas, showing thus its brittle nature. In the rock-mass this component is approximately arranged in a parallel direction; between crossed nicols it extinguishes light parallel to the longer side; its polarization-colour is vivid, coming near to that of muscovite, but it may be easily discriminated by the want of nacreous lustre, and by a peculiar wavy structure when viewed between crossed nicols. I conjecture this mineral to be *margarite*. Stauroscopic examinations show on a cleaved face a wide optic angle, so much so that the centres of concentric rings scarcely lie within the microscopic field. The dispersion of the optic axis for the red is smaller than that for the violet; i. e., $\rho < \nu$, while that of muscovite would be just the reverse. The biotite is of the usual brown colour, and is interlaced with the lamellæ of margarite; it is found in far less quantities than the other mica. The quartz fills up the interstices of the other components, and is consequently wedge-shaped; it shows intense polarization-colours. Occasionally grains of feldspars may be noticed.

A *c) Garnet-Biotite-Schist.*

There is no rock which varies so greatly in its outward appearance as the garnet-biotite-schist. This is in the main due to the varying quantity of biotite. The one extreme is a highly quartzose schist of a greyish colour, with its characteristic vitreous lustre, and its weathered portion usually coloured brown. Micaceous zones are indicated by dark stripes on the transversely fractured surface of the

rock. The other extreme is a rather dark, imperfectly schistose, banded rock with red crystals of garnet sprinkled all through it. The microscopical components are the same in both varieties. The main mass is made up of quartz-grains with the tombac-brown biotite between them. The biotite is found in the substance of the quartz as enclosures, but the grains of quartz are comparatively free from liquid and gas inclusions. Muscovite is here wanting.

Accessories are sillimanite in fine radiating tufts (Fig. 3, Pl. XXVI), prisms of zircon, and clumps of iron glance. Garnet is a never-failing but accidental component. In the first, the quartzose, variety of the schist the garnet occurs in minute, *almost colourless* dodecahedra, while in the second, the basic, schist it is somewhat large, granular, and cherry-red. *The colour of the garnet seems to have some connection with the quantity of biotite present in the rock;* for, in the dark variety with abundance of the black mica, the garnet is *red*. This mineral is extremely rich in enclosures of quartz, and in negative crystals filled with air, so as to make it appear like some crystals of staurolite.

A *d) Hornblende-Biotite-Schist.*

This is exactly the same in its external appearance as the gneiss-mica-schist, already described, differing, however, from it by the presence of hornblende as an essential component. The rock is grey, and splits easily into an even tabular plate. The feldspars, both the monoclinic and triclinic, make up the greater part of the mass, while the amount of quartz decreases as they increase. The deep-brown biotite and the bottle-green hornblende are intimately plaited together, showing none of their crystallographic outlines. The zircon and apatite, both in the form of grains, are especially abundant in this rock. Locality: Nishida, east of Tanagura, where the rock forms a

member of the complex of amphibolites and mica-schists ; otherwise its distribution is not so wide-spread as that of the other rocks.

B. Titanite-Amphibole-Schists.

They form manifold alternations with the preceding rock. They are the black, highly crystalline schists with the plane-parallel structure, whose transverse section shows interbanded, thin, light-coloured zones, recurring hundreds of times even in a small chip (Fig. 1, Pl. XXVII). If we move upward to a higher horizon, the rocks become perfectly schistose, cleaving easily into a papery slab ; and as their texture is not so compact as that of mica-schist, they easily fall into a bluish-black, ashy powder on their weathered surface.

The (*a*) *black zone*, when examined under the microscope, is seen to be made up of a bottle-green hornblende, whose pleochroism is distinct, but not so pronounced as that of the brown variety, a, yellowish-white, b, oily-brown, c, greenish-brown ; the absorption $c > b > a$.

Isometric *plagioclase-polygons* [1] are present, besides the hornblende, in clear crystals free from any interpositions. All the polygons, so formed from the disposition of neighboring grains, show undulatory extinctions which sweep concentrically from one zone to the other in the crystals, as the section is rotated. Only a few grains (1.3 mm.) are coarsely twinned, with the angle of extinction of 7°-10°, or 3°-4° symmetrically with respect to the twinning suture, so that here we have probably before us an andesine feldspar.

The lamellæ of biotite, with the interleaved bacillar hornblende, are oily-brown or green, but through weathering have become so entirely decolorized as to be readily mistaken for a typical musco-

1 *Vide ante*, p. 246.

vite. Examined from the base, the mica has a small optic angle, and consequently should be considered as a variety of biotite. The mica is present in fluctuating quantity, and it never takes an important part in the composition of the rock, but still it should be considered as a characteristic ingredient of the amphibole-schist, since it is entirely wanting in the series next above it. Though it occurs in meagre quantities, it may be readily recognized on the plane of schistosity by its *gold-yellow, glittering lustre.* During field work we meet with several amphibolites, all having nearly the same appearance, but belonging to quite different horizons; *the presence of the biotite should, in these perplexing cases, be taken as a criterion for the identification of the amphibolite of this series.* We name this rock in the field the *biotite-amphibolite* in order to discriminate it from other kindred varieties.

The (*β*) *light-green bands* in the schist, already referred to, differ in many respects from the (*α*) *black zones* rich in hornblende, by the presence of a *light-green augite.* Here the grains of feldspar are of minor dimensions, and for the greater part its substance has been changed into an aggregate of a colourless, fine fibrous, confused mass, which between crossed nicols displays highly chromatic, aggregate polarization-colours. The intact part of the feldspar appears, therefore, here and there in a sporadic manner within the above-mentioned micaceous mass, which seems to be identical with the so-called *pseudophite.* This white band, sometimes attaining the breath of 2 or 3 cm., is moreover very dirty, owing to an admixture of titaniferous iron and highly refractive grains of titanite (1 mm.) forming a rim of iron-ore, to which we shall have occasion to return in the sequel.

The *augite* (Fig. 12, Pl. XXIII.) already referred to, occurs in this band in great abundance, taking the place of the hornblendic element, and even of the feldspathic component. It is found always in

the form of isometric grains; sometimes, however, elongated ones (1 mm.) are observed, and along their longer axis run a few suture lines which are traces of the characteristic cleavage of augite (Fig. 12, *d* and *e*). The extinction of light takes place at a very high angle, usually 30° or more, with regard to the trace of the cleavage. It is colourless or faint-green, indicating the paucity of iron in it. The colouring pigment, slight as it is, is, however, not uniformly distributed, the periphery is rather of a lighter shade than the interior. The mineral presents another very characteristic feature which is here worthy of short consideration. There are many short, black streaks, which run strictly parallel to the cleavage-direction, and are confined exclusively to the interior of the crystal (Fig. 12, *d* and *e*). Examined with high powers these interpositions are found to be nothing but negative, long, rectangular spaces, filled with air, or water with air-bubbles, and the grains consequently look not unlike the diallagic modification of augite.

Recently, Prof. Judd advanced a beautiful theory of the schillerization—a phenomenon produced through the secondary infiltration of some substance into the spaces formed by certain solvents along the so-called "solution-plane," or the plane of chemical weakness, when the rocks containing feldspar and also augite are subjected to high strains at great depth.[1] In the last number of the *Mineralogical Magazine*[2], Judd has again submitted augites to the same line of treatment which he had so earnestly advocated in his former papers. The orthopinacoid of augites, he says, is the normal solution-plane, and if once the twinning lamellation is induced to develop in crystals, then along the planes of chemical weakness just the same thing may be effected as in those of labradorite. *I can not but*

1 Mineralogical Magazine, Vol. VII. (1886).
2 Ibid, Vol. IX. p. 192.

think the present augite represents in the non-aluminous group an incipient stage of the formation of the so-called pseudo-hypersthene of an aluminous augite.

Sometimes grains with the augite-cleavage are observed (Fig. 12, *a*, *b*, and c), and these basal sections are marked with numerous spots which are nothing but the cross-cut of the cylindrical holes, well seen on the longitudinal sections (d and e) of the mineral. There seems, however, no regularity in the arrangement of these dots. The pleochroism is faintly observed only on the clinopinacoid, when the interior portion is of a darker shade than the periphery; and the absorption is the strongest when the principal axis coincides with the principal section of the lower nicol. Some grains show intense polarization-colours between crossed nicols, nearly equal to those of augite or olivine, and these, when closely examined, always extinguish light in oblique directions with reference to a few cleavage-traces. The grains with straight extinction are on the contrary very dull, ranging from grey to light-brown.

The augite is scattered through the entire mass, to the extent of nearly the half, and when it occurs associated with a rather green hornblende which is present only in small quantities, it is imbedded within the substance of the hornblende (Fig. 3, Pl. XXIII), each having different optic orientations, as shown in the figure.

From the whole habitus I consider these *light-green grains* to be the *salite* of Prof. Kalkowsky, who was the first to point out the wide distribution of this mineral in amphibole-schists. Unfortunately his original paper is not accessible to me, and a strict comparison of the salite from the Oberpfälzer Waldgebirge with the Japanese mineral is at present a matter of impossibility. Prof. Becke[1] has also given a

1 *Die Gneissformation des niederösterreichischen Waldviertels.* Tschermak's mineralog. und petrogr. Mitth. Bd. IV, p. 189.

short description of it, and its wide distribution in the amphibolites from the Waldviertel of Lower Austria.

Apatite, which is so far not found in the hornblendic zone, is present here in large quantities in the form of grains of nearly the same size as that of the salite. It is not prismatic in habitus as usually found in rocks, and in the present case, one might take it for a light-coloured salite, but its faint-blue polarization-colours, its characteristic dot-like enclosures, and its hexagonal cross-section preclude its being confounded with the augitic mineral.

Lastly, the most interesting component found in the light-green zone is the *titanite* (Figs. 5, and 6, Pl. XXIII). It is not found in well-finished crystals, but in those forms resembling rolls of butter (*weckenförmig*). Some are spindle-shaped, tapering at both ends into sharp points. Others are approximately sphenoidal, being fissured transversely at various points across the crystals ; along these fissures and also at right angles to them lie the directions of maximum extinction. We have here probably a basal view of the titanite. The other very obtuse rhombs are its clinopinacoids with oblique extinctions. There are still others which indicate no signs whatever of crystallographic forms, but present shapes like falling drops from the melted end of candle-wax.

In some of these clumps there exists a black, formless mass in the centre, which I presume to be a *titaniferous iron* (Fig. 5). At times the black cores are of a tolerably large size, and the titanite forms but a very thin coating around them. The titanite is highly refractive, and has dark margins and a chagrined surface, due to the total refraction of light that enters from the other sides. Its substance is not very clear, and has some enclosures whose nature could not be made out, owing to the high refraction of the titanite. The polarization-colours are rather weak, ranging from

brown to grey ; but some drop-like grains are highly chromatic and have a striking similarity with the olivine grains which are also said to be found in some amphibole-bearing schists. Prof. Kalkowsky[1] has mentioned the occurrence of *olivine* grains which cluster round the iron-ores, and *the figures of the olivine (glinkite) given by him have a remarkable similarity with the above-mentioned grains of titanite with the enclosed titaniferous iron.*[2] I have, therefore, some doubts as to the real nature of the present titanite, and consequently have had it subjected to a chemical examination which proves the presence of titanium in it.

The titanite grains in the *basic*, hornblende zones mostly *possess black cores*, and the minerals which accompany such titanite are biotite and hornblende, both being ferriferous components, while in the *acid*, salite band the grains are usually *free from the black iron-ore.* The first modification of titanite may be fairly compared with the so-called titanomorphite, resulting from the decomposition of the titanic iron ; but in the present case I can not conceive the titanite-margin to be derived from the black core ; they are original, and should not be taken for titanomorphite.

The hornblende in the salite-band is pre-eminently green and pleochroic ; the feldspar is one of the striped varieties. There is also

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1 *Die Gneissformation des Eulengebirges*, p. 37-38. See also Dr. E. Dathes work: *Olivinfels, Amphibolit und Biotitgneiss von Habendorf in Schlesien*, in the Jahrbuch der königl. preuss. geologischen Landesanstalt für 1888, p. 322-324. The amphibolites of the gneiss formation of the Eulengebirge seem specially rich in the olivine grains, as may be judged from Kalkowsky's and Dathe's work. So far as I know, I have as yet not come across the olivine in any of the genuine amphibolite-schists of Japan. The peridotites and serpentines, however, often contain that mineral ; but they occur only in the form of intrusive bosses, sheets, and dykes in the archæan members.

2 Mr. J. J. Harris Teall has given a similar figure in Plate XLVII, fig. 3, in his "*British Petrography*" with a note that it "shall represent a kernel of iron ore zoned by sphene." Unfortunately he was obliged to postpone all detailed references to this mineral to some future occasion, notwithstanding the fact that the plate had been prepared of a glaucophane-schist from Anglesea, in which the above-mentioned titanite is said to occur.

a clear, unstriped feldspar in the *hornblende zone*, which I also place in the plagioclastic group.

The above notes chiefly refer to the rock brought from Kamada, 1 ri south-west from Takanuki. Having given a general description of the amphibolites, we may now briefly consider their many modifications.

B *a) Titanite-Biotite-Amphibolite.*

This is the commonest type found all over the region included within the terrain of the present series, so that the citation of its occurrences would be quite redundant. It is thin-banded, and has a plane-parallel structure. Sometimes, however, massive modifications are not wanting; still their transversely fractured surface always shows a banding of the white, feldspathose, and black, hornblendic zones. The hornblende is brown and pleochroic, the titanite-wedges and the lamellæ of biotite are interposed between the bacillar amphiboles. The clear, polygonal feldspar is of a rather large size.

The interbanding white zone is in the main made up of the last mineral, and its grains are minute. Intermixed with these there are chains of titanite-grains with the drop-like titaniferous iron. The best exposures are found at Shimo-Yamagami near Matsukawa.

B *b) Titanite-Salite-Amphibolite.*

This rock, so far I am acquainted with it, is only found at Kamada, and its general description has been already sufficiently given in the preceding pages. It is a deep-black, somewhat granular, thick-banded schist, alternating with the light-green bands (2-3 cm.) of salite. The hornblendic zone is almost entirely made up of a bacillar amphibole; and through weathering a glittering, gold-yellow biotite comes to view on the surface of the rock.

B *c) Titanite-Feldspar-Amphibolite.*

This approaches in its outward appearance to the first variety, but it may be readily distinguished from the mica-bearing amphibolites by the absence of biotite. Also for the same reason the plane-parallel structure, which is macroscopically observable in all hand-specimens when the biotite is present, is not perfectly developed; the cross-section is, however, fine-banded, owing to repeated alternation of the white zones of feldspar with the black ones. The feldspar and hornblende are nearly of the same size, and are fine when compared with the two preceding modifications.

The hornblende is grass-green and pleochroic, bacillar in form, and is arranged approximately in parallel directions; the feldspar is clear, and polygonal in outline. The particles of the latter are minute and granular in the white zones, and the titanite-grains, occurring with them, with their usual black cores, are chained one after another, parallel to the banding of the schist. Weathered rocks look not unlike a sandstone-mass. The specimens examined are those from Sōri near Ishikawa, and Yamagami near Matsukawa. I saw some traces of copper pyrites in them.

B *d) Biotite-Amphibole-Gneiss.*

This occurs in the titanite-biotite-amphibolite as a lenticular mass of scarcely half a metre in breadth, and can be easily distinguished from all others of the present series by a fine granular-lamellar structure. A transversely fractured block shows in the clearest manner the mode of aggregation of the components. The black, flame-shaped, patches are nothing but granular accumulations of a greenish-brown, bacillar hornblende with traces of the basal cleavage, and the white dots are porphyritic, untwinned feldspars, nearly all completely changed into a

muscovite-aggregate but with some part intact on the periphery. The rest of the rock-mass is built up of quite unchanged, colourless feldspars with some grains of quartz, which on account of the parallel position of the dark-brown biotite assume a more or less wavy structure. Only a few grains of the feldspars exhibit twinning lamellation between crossed nicols; consequently it is difficult to say whether we have to do with plagioclastic or monoclinic varieties, but probably the porphyritic feldspar belongs to the latter family. A black, highly lustrous iron-glance may be observed, but not titanite. The specimen here described comes from Sōri; but this gneiss might, no doubt, be found in many other places by close examination in the field.

VII. Petrography of the Gozaisho Series.

A. *Amphibolites of the Gozaisho Road.*

We are in the habit of allowing so wide a latitude to amphibolite or hornblende-schist, that the name alone gives scarcely any clue as to the real nature of the rock a petrographer denotes by it, for the term amphibolite which includes rocks differing greatly in their external appearance and the nature of their component-minerals, as well as in their genesis, that is, whether they are metamorphic schistose diorites or really stratified schists. Therefore, it will be well here to give certain prominent features which eminently characterize our rocks, with the view of distinguishing them from the titanite-amphibolites of the Takanuki series, already sufficiently described.

Besides the great difference which exists between the horizon of the rocks I am now describing, and that of the other series, the following points are to be mentioned: 1) Perfectly fissile, evenly plane-parallel structure is to a certain extent common to the rocks

of both series, but the upper part of the present rocks becomes rather compact, slaty, or thick-tabular ; 2) colour more greenish or greyish ; 3) absence of titanite and salite, compensated for by the presence of chlorite, epidote, magnetite, tourmaline, and sometimes rutile ; 4) structure not granular, but linear or parallel and more or less compact, the last character especially giving solidity to the rocks, so that they withstand atmospheric action better ; 5) macroscopically, the mineralogical components are scarcely recognizable in the green slaty rocks ; 6) microscopically, the ingredients, especially the hornblende, are in parallel and linear alignment, so that a slide made parallel to the schistose plane presents the same side of the minerals, whereas in the rocks of the Takanuki series basal and longitudinal sections of the component-crystals are visible in the same slide, lying confusedly together ; 7) hornblende mostly needle-shaped or prismatic in habitus, while in the other, it is polysomatic or tabular, or broad if prismatic ; 8) colour of the hornblende light-green, and not intensely-green or brown.

The rocks comprehended under the present group vary greatly as well in their external appearance as in their inward structure, to such an extent that they do not allow of characterization in a few words. They differ stratigraphically as well as petrographically in mineralogical composition being accompanied by a change of structure. From a highly crystalline, somewhat granular member bearing the stamp of a genuine crystalline schist to a compact, green, slaty assemblage, they grade one into another imperceptibly without any marked break. This may be traced advantageously in coming down eastward, along the rapids of the Samegawa, from the plateau of Takanuki to the boundary of tertiary hills, at the very junction of which stands the small village of Kadōno (Profile C-D, Pl. XXV.)

I begin with the lower member, a highly crystalline amphibolite.

a) It is a schistose, imperfectly fissile, evenly plane-parallel, dark-green, slaty rock, built up of multifarious alternations of white and black bands, comprised of microscopically fine, glittering needles of a black hornblende and saccharoidal, milky-white feldspar, disposed, as I have stated, in fine zones. Such rocks differ so little from those of the *Takanuki series* in their external appearance as to lead one to suppose them to be quite identical. However, on close examination marks of distinction may be easily perceived. For besides the fineness of texture which characterizes the present rock, *the spangling gold-yellow biotite can not be seen on weathered surfaces of it as on those of the titanite-amphibolite*[1] *; these surfaces are dark-green and dull.*

Under the microscope the hornblende appears compact, and with irregular outlines, and also in ragged plates which are either short and oblong, or have the shape of slender prisms. The small prisms are arranged more or less parallel. The broader plates are less parallel, crossing each other at various angles, and giving a coarsely felted aspect to the section. In the plates very fine striations run parallel to the base. As all the crystals of the hornblende are not disposed in parallel direction, so basal sections are sometimes observed in the combination of prism and clinopinacoid. The mineral is of a dirty-green colour, and pleochroic, varying from green to oily-yellow. The general mass is made up of feldspar (and some quartz?) with crystalloids of hornblende. The feldspar is not uniform in size, and is polygonal in outline; its polarization-colour is weak, showing undulatory concentric extinctions; its substance is clear and fresh. Only a few flakes of biotite are to be seen on the cleaved plane. Microscopically the biotite may be considered as an accessory, occurring associated with the hornblende aggregates as brown, fibrous lamellæ,

1 See *ante* p. 251.

devoid of external outlines. Masses of iron glance, both deep red and opaque modifications, adhere to the crystals of the hornblende, and also form local accumulations in them. This rock crops out at the district-boundary of Kikuta and Higashi-Shirakawa, on the Gozaisho road, being cut sharply by hornblende-granite, where the latter assumes a more or less schistose structure (GHG, Profile C-D, Plate XXV).

b) Not far from the last locality, and directly overlying the preceding, we find a schist which is surely a modification of the rock just described. It is a greenish, fine banded, imperfectly fissile, feldspathose schist, with sericitic membranes and the tufts of a brownish tourmaline on its cleaved surface. Under the microscope a bluish-green, pleochroic hornblende assuming long, sheaf-like forms, is seen in more or less parallel alignment, but locally the crystals are thrown indiscriminately together so as to form a more or less intricate felt-work. The interstices between them are occupied by the fresh, clear feldspar which is *sharply bounded, polygonal, and well adjusted with the neighbouring polygons.* These polygons are peppered through with grains of black iron ore which, by reflected light, presents a bluish-black lustre and lamellar structure. It is, therefore, iron glance, but not magnetite, with which it is often confounded. The heart- and knee-shaped twins of *rutile* are scattered through the section ; *it must be expressly remarked that this mineral has hitherto not been observed in the allied rocks of the Takanuki series.* This rock occurs associated with the tourmaline-bearing mica schist, to be described in the sequel.

c) Some of the rocks higher up in the series, associated with schists such as that just described, are very similar in appearance to common chlorite schist. Indeed they are compact, bluish-green, rudely fissile, slaty rocks which, on cursory examination, might be very often taken for chlorite schists. Examined under the microscope, the predominating mineral, the hornblende, is seen to be present in

the form of an intricate felt-work of fine prismatic crystals, appearing not unlike the needles of sillimanite. Only a little feldspar is found as a granular, weakly polarizing aggregate, in which actinolite is rare. The general mass is full of tea-brown, hexagonal tablets and grains of opaque iron glance.

d) The next in ascending order, and forming the basement of the temple of Gozaisho, is a schist which not only differs in its external aspect but also in its mineralogical composition from those of the preceding rocks. The appearance itself suggests at once that the rock has suffered a great physical change by dynamic metamorphism to such an extreme degree, that the zones of feldspar, now appearing dull and saussuritic, have been so torn and convulsed as to assume a puckered aspect. The rock is finely crystallo-granular, massive and slightly fissile, and imperfectly banded with milky-white, feldspar zones.

The microscope reveals that the schist is composed of a bluish-green hornblende, dirty, greenish-brown biotite, crystals and grains of magnetite, all arranged in parallel lines, and lapped over by thin flocculent chlorite. A transverse section of the rock admirably discloses the mode of arrangement in full detail. A greyish-green biotite and the dust of magnetite together make up special bands, running through the rock and flowing around the aggregates and sometimes large, well-defined crystals of magnetite. Above and below, the band is bordered with an accumulation of magnetite, whence the bluish-green, sheaf-like hornblende shoots forth in different directions into the fine aggregate of white, feldspar zones. Some feldspar occurs in the shape of large, irregular grains forming veinules within the microcrystalline mosaic of the same mineral. The feldspars are limpid, but some show traces of alteration, and are traversed by many fissures and chains of liquid-inclusions with air-bubbles, in a direction at right angles to the plane of schistosity of the rock.

I confess that I am totally unable to distinguish quartz from feldspar when their grains are thrown together in a mosaic aggregate ; but judging from the massive, feldspar-hornblende rock, from which presumably the present one seems to have been derived, I naturally deny the presence of quartz. It is particularly misleading that the larger crystals of feldspar, which must have been and still must be subject to peculiar strain by pressure in such a metamorphic rock, display polarization-colours of so high order as to lead one readily to take them for quartz ; but from time to time a few stripes of different colours may be noticed, which point to the latent existence of twins in the feldspar. In saying so, my notion is not strictly to preclude the presence of quartz, as this is reasonably supposed to be formed in the metasomatic changes, which any rocks, especially of eruptive origin, may suffer during an orogenetic movement of the mass. I simply mean that grains which may beyond doubt be regarded as quartz have not been observed. The bluish hornblende bears evident mark of having been produced in some secondary way in its sheaf-like form, frayed at both ends and tufted together in acicular bundles. Minute grains of epidote occur mixed with accumulation of magnetite.

e) The rock lying east of, and consequently overlying, the metamorphic schist just described, is a massive, fine-granular, green rock without any fissile structure in a hand-specimen, though a few rock-cleavages might be found in natural exposures. It appears like a rock altered under the influence of contact action of some eruptives. The surface is speckled with white dots, especially on weathered specimens, indicating the presence of much feldspar.

The granular structure of the rock may be better understood by examining a slide with the microscope. It is seen to be mainly made up of hornblende in ragged, sheaf-like or fibrous masses, frayed out at the ends into radiating tufts. The hornblende is disposed in

such a confused manner that within the microscopic field all possible sections of it may be seen, and hence the granular structure of the rock. The hornblende is green at its margins, but light-brown at its centre; thus giving rise to zonings of colour of which, the peripheral, deep shade is surely due to a slight change in the substance of the amphibole. When the axis of mean elasticity b coincides with the short diagonal of the lower nicol, the differences in shade are most marked, while in the position at right angles to the former, *i.e.*, c, the whole crystal becomes greenish in colour, and the zonings thus disappear.

The interstices between the hornblende are occupied by feldspar crystals which appear quite homogeneous by simple light, while between crossed nicols they are resolved into dot-like, minute grains imbued with the feldspar substance, and the arms of the interference-cross sweep round as the section is rotated, after the manner of a spherulitic mass of chalcedony. It may be fairly inferred from the optical deportment of the rock that after its granulation and crushing, *its temperature was raised by orogenetic movement so far as to partially melt the feldspar into a more or less plastic mass, or else that a molecular rearrangement took place in it at a comparatively low temperature.* The substance of the feldspar is made dusty by accumulation of microscopic grains of epidote and crystalloids of hornblende. Formless masses of an opaque iron ore are plentiful, surrounded by a dull, white, granular accumulation, probably of leucoxene.

f) The one occurring to the east of the last-mentioned, and near the last house, the westernmost of Ōdaira, locally called Saragai, is a medium-granular, massive rock of a dark-bluish colour, showing no signs of fissility. This I considered in the field to be a fine structured variety of a gabbro and under the microscope I find it differs in no essential point from this. The habits of the hornblende, magnetite, and interstitial feldspar are exactly the same. The needles of secondary

hornblende, detached from the larger crystals are, however, plentiful in the apparently homogeneous feldspar.

g) Finally, we come to the uppermost of the rock-series, now under consideration, which is found along the banks of the Samegawa, at the village of Odaira lying close by Negishi, not far from the boundary of the tertiary terrain under which the rock gradually dips to be seen no more in this region. This rock represents the extreme phase of development of the thick series of Gozaisho, the corresponding other extreme is, as has been already stated, the one found near the west end of the Gozaisho Narrows, just at the district-boundary of Kikuta and Higashi-Shirakawa, and which I have already proposed to call the *feldspathose hornblende-schist.* The present rock appears at first sight as if it were made up of silt, ashes, and the paste of volcanic mud, consolidated and pressed subsequently to its present form. It is a rather *greyish*, rudely fissile, slaty rock, simulating very much the appearance of the *clasio-amphibole slate of the Mikabu series*[1] which forms the basement of the palæozoic group of Japan. The present rock is glossy in appearance on a cleaved face, and the greyish shade seems to be caused by the light colour and acicular habitus of *actinolite*, as well as by the presence of minute grains of epidote, which make up no small portion of the bulk of the rock.

Under the microscope almost the entire rock is seen to be built up of needles and fibrous shred-like masses with a decided tendency to parallel arrangement. Exceptional cases are not rare, as there are often-times found confused aggregates of fibrous matter, concealed by chloritic membranes, having an appearance very much like the antigorite-variety of serpentines, especially when viewed between crossed nicols. The actinolite is of a light-greenish colour and weakly

1 B. Kotō; "*On the so-called Crystalline Schists of Chichibu,*" in which the minute structure of the amphibole slate has been considered in full detail. This Journal, Vol. II, p. 112.

pleochroic. The interstitial, half-granulated feldspar, probably albite, is visible through the flocculent chlorite; and the whole rock is peppered through with almost colourless grains and slightly yellowish crystalloids of epidote.

B. *Mica-Schist.*

The mica-schist, interbanding with the amphibolites, may at once be discriminated from those of the complexes of mica-schists and granulitic gneisses of the Takanuki series, by its coarse-lamellar texture and glossy iron-black lustre. Common mica-schists are, as a rule, highly quartzose, and the biotite that enters into their composition is usually scaly; this rock, however, is highly micaceous, being for the greater part made up of lamellæ, but not the hexagonal scales, of biotite. The rocks classed here as mica-schist exhibit within narrow limits a considerable diversity, as well in their outward appearance as in their microscopic aspect. Therefore, they may be conveniently divided into two varieties.

a) A coarse-lamellar, somewhat wavy structured variety is basic and rich in feldspars; the tombac-brown lamellæ of mica lap one over the other, forming a thick, continuous membrane, and constitute undulating zones with the quartz-feldspar aggregate. A cleaved surface is not even, but lumpy or nodular, due to the local swellings of quartz in the schist, into spindle-shaped assemblages well seen on the transverse fracture, and these give a gnarled or knotted appearance to it. In its outward aspect this rock resembles the so-called "*Garbenschiefer*," or the graphite-sericite-schist of the Sambagawan series of the author,[1] differing, however, from the last-mentioned in the presence of true biotite instead of a green, fibrillated, sericitic mica. The feldspar occurs in polysomatic forms; simple twins are often made visible by

1 *On the so-called Crystalline Schists of Chichibu;* This journal, vol. II, p. 97.

the behaviour of different polarization-colours in the two-halves, as well as by unequal angles of extinction on the right and left. Its polysynthetic lamellar structure is rarely to be observed, and then only partially, being chiefly confined to the margins of crystals, and coming to an end abruptly near their middle. Maximum-extinction takes place usually at very small angles with the twinning-sutures, a fact which compels me to place this feldspar in the andesine series. The great majority of feldspars occur, however, in simple crystals, and should therefore be considered as orthoclase. Some of the orthoclastic feldspar have acquired an "eye"-like habitus, being of somewhat larger size than the neighbouring grains, and encircled by the foliæ of biotite. The feldspar-"eye" has been transformed into scales like muscovite, and encloses a mass of iron-glance disposed in such a manner as to assume a fluidal structure. Opaque *iron-glance* (not magnetite) enters into the composition of the schist in such large quantity as would allow one to speak of the rock as being literally charged with iron ore, and is found especially in those parts where the foliæ of biotite have been brought together into a thick heap. Taking into account the considerable amount of feldspar present in the rock, I propose to call it the *feldspar-biotite-schist*. The rocks examined were brought from Shimo-ichinokaya (Sono-ana), Iwa-mae gōri; and Kamesaku, $1\frac{1}{2}$ ri east of Ōta in Hitachi.

β) Another modification, a true biotite-schist, is rather fine-granular, black or greenish-black, and a perfectly fissile, evenly plane-parallel schist, being made up of alternations of thin bands of biotite and quartz. A typical specimen of this rock is found at Gongendō (Kami-Yoshima), not far from the town of Taira. *Feldspars* seem not to be present, and if present are rare. *Tourmaline* is the most characteristic accessory component, and through its

presence, I think, I may discriminate this schist from allied micaceous rocks. The *tourmaline is of greyish-brown*, or *sometimes of greenish-blue colour.*

(1) Of these the greyish-brown kind occurs in the form of prisms with imperfect terminations, which enclose a large quantity of the dust of iron glance. The mica occurring associated with this variety of tourmaline is a *brown* biotite in irregular lamellæ, frayed out at the margin into a felt-work of fibrous mass ; while the general matrix in which it is imbedded is a mosaic of round grains of quartz. There are other patches of much larger, angular interlocked quartz forming irregular, sinuous bands in which biotite is proportionally rare, while in the micaceous portion both muscovite and the brown biotite are plentiful. The quartz is ideally pure, and in this point the rock differs from those of the lower horizon. Round-edged crystals of apatite are sporadically present.

(2) The schist with a dirty *brownish-green* biotite, of the same habitus as the preceding, appears somewhat like a chlorite schist and contains the prismatic, *greenish-blue tourmaline* which clusters at some places into a confused aggregate, a peculiar habitus not observed in the other mica-schist. Angular grains of feldspar are found intermixed with quartz, which through weathering may be readily distinguished from each other. The yellowish-brown needles of rutile occur in the foliæ of the biotite in divergent-radial arrangement. Garnet, the commonest accessory, is, however, not present in all the schists of this group. *Iron glance is always more or less present, taking the place of magnetite in the other rocks*, lying above and below this one.

C. *Garnet-Chloritoid-Quartz-Schist.*

Intercalated between the chloritic amphibole-schists of the upper

Gozaisho complex, we find a quartzose rock of an uninviting, dirty-greyish appearance with a characteristic vitreous lustre on its fractured surface. Looked at from the side it seen to be formed of fine banded, slightly rosy, garnetiferous stratulæ alternating with other greyish ones. Under the microscope it is seen to be mainly made up of quartz, garnet, and chloritoid, severally traversed by veinules of quartz. The garnet dodecahedra are plentiful, the rosy zone being especially so mottled by aggregates of this mineral as to make the section appear dull. The colour of the garnet is faintly red; small crystals of it are, however, colourless.

The chloritoid occurs in lamellar masses with irregular outlines and also in rounded forms. The latter are of plum-green shade, non-pleochroic, and indifferent to the action of polarized light; sections of the former exhibit a few cleavage lines from which the direction of extinction deviates at an angle of about 15.° The pleochroism is distinctly pronounced, the rays vibrating in the direction of the principal axis are plum-green, those at right angles to it, olive-yellow. The thick, brittle, lamellar mass of this mineral has a tendency to aggregate at certain spots, and the crystals of garnet are here particularly abundant. The characters of our chloritoid agree well in essential points (Photogramme 1, Pl. XXVI) with those of the Austrian occurrence whose description has been given by v. Foullon[1]. This rock is found at Naka-Misaka, near a water-mill, Iwamae gōri. Another rock belonging to the same category was taken from near the temple of Gozaisho.

D. *Amphibole-Picrite.*

The olivine rocks seem to be of a wide distribution within the

1 *Ueber die petrographische Beschaffenheit der krystallinischen Schiefer*, etc. Jahrbuch d. geol. Reichsanstalt, 1883, p. 220.

confines of the Abukuma plateau, as may be judged from a number of specimens which have been brought home from different localities by my colleagues; but their modes of occurrence are unfortunately very little known to me. T. Kochibe[1] was the first who acquainted us with the occurrence in the Abukuma district of a dunite which was then considered as an archæan schistose member. S. Ōtsuka, however, found it occurring in intrusive dykes within pyroxenites of the palæozoic age. "It is a compact or fine-granular, dark-green or light-brown rock, essentially built up of *olivine*, *chromite* and a little *hypersthene*. A fresh dunite is only known from Ishigami and Aka-saka-Higashino, near Ishikawa in Iwaki; and Saimaru, Taga-gōri, in Hitachi."

I myself collected some specimens from other localities entirely new to Dr. Harada. One was found as an intrusive boss through a salite-amphibole-tourmaline schist, at Naka-Misaka, and another at Yama-gami, near Takanuki, the latter forming a dyke through a complex of gneiss-mica schist and titanite-amphibolite. The peridotite seems to me from its modes of occurrence to be of a decidedly irruptive origin, injected through various rock-groups of different ages (Profile 4, Pl. XXIV). But whether there are any near relatives of the peridotite, which might substantially be connected at their root with the olivine rock, or whether it is pressed up alone as dykes through several fissures, quite independent of magmas of other rocks, I am as yet not able to assert definitely.

It has been known for a long time that basic rocks at their points of contact with others are particularly rich in olivine. Extended researches made by Dr. E. Stecher[2] have well shown, how the proximity of the intruded rocks could exercise an influence upon the

1 T. Harada; *Die japanischen Inseln*, p. 75.

2 *Contacterscheinungen an schottischen Olivindiabasen*, T. M. M. IX, 1887, p. 146 et seq.

intruding basic magma in the formation of olivine in the latter. In several of the papers by Professors Judd and Bonney it is clearly pointed out, how fluctuating are the relative quantities of the component minerals of basic rocks. It is frequently observed that, by a slight textural modification, dolerite (diabase) gradually passes into gabbro, by the disappearance of feldspar, into picrolite, by the disappearance of augite, into troctolite, and, by the disappearance of olivine, into eucrite; while by the excessive development of accessory constituents like enstatite and picotite fresh varieties such as lherzolite may arise.

The prevalent rock, and at the same time the foundation stone of the Abukuma, is of intermediate chemical composition, to, *i. e. the syenitic granite*, which is specially liable to form transitions to *tonalite*, *diorite*, *monzonite*, and eventually to *gabbro*; and it seems to me highly probable that the olivine rock in question represents the extreme basic member of the syenitic magma, which has sent out various offshoots in the form of apophyses from the main mass in the bosom of the earth. Being influenced by cooling surfaces which must have been comparatively large and many in such narrow fissures, a selective crystallization has been induced in the magma, whereby olivine has been formed at the expense of the other minerals; and thus we have several dykes filled up with rocks of a peridotic composition.

The olivine rock which came under my notice in the field should be grouped together with *amphibole-picrite*. It is always very massive in appearance, rarely exhibiting banded structure. Its irregular, rounded blocks are often covered with a thin coating of a deep-red colour due to decomposition, beneath which, however, the rock is surprisingly fresh and of a dark greyish-black. Under the microscope it seems to consist of a sheaf-like, colourless *hornblende* (tremolite) piercing through the granular aggregates of olivine. The latter is

encircled by fibres of chrysotile which separate individual grains from each other; and as several grains behave optically in exactly similar manner, they must have been formerly parts of a larger individual which by serpentinization has now become detached and isolated grains. The olivine-core is filled with the dust of chromite, and also with round or rectangular grains of the *spinel* group. The spinels are isotropic, and highly refractive, and have therefore dark margins. Some of the opaque aggregates which might easily be confounded with chromite are surely octahedra of spinels. Examined with high powers the minerals are found coloured either dark-brown or green; the former may be *picotite*, the latter *pleonaste* or *hercynite*.

The colourless tremolite is bacillar in form, some rods attaining 2 mm. in length; their terminations are never perfect, being always resolved into tufts of fibres which, in turn, eventually pass into a filamentous aggregate of serpentine. The substance of the tremolite is not compact, and seems to be extremely thin; it is also traversed through its whole stretch by fine divisional lines parallel to the principal axis, in consequence of which the mineral displays only aggregate polarization-colours. That the tremolite is the primary component and not a secondary one is proved by the fact that it penetrates the remnant of the olivine, and also cuts sharply the edges of the dismembered grains of the same mineral.

The final product of degeneration of both the tremolite and olivine is the well-known serpentinous mass; the one originated from tremolite appears in the form of splinters of wood, which are thrown together in such a manner as to form an imperfect "bladed" structure (*Balkenstructur*) of *antigorite;* while that resulting from olivine is the fibrous *chrysotile* which produces a characteristic mesh-work, with aggregates of chromite along the original fissures of the olivine.

A rock from Saimaru in the collection of the Geological Survey is

a pure, fresh *dunite*, entirely made up of olivine grains with only a little serpentinous matter; that of Akasaka-Higashino belongs to the same species with exactly identical mineralogic composition and habitus, but differs from the former in the particular that it abounds with interposed *picotite*.

VIII. Dyke-Rocks.

A. *Pegmatophyritic Dykes.*

Along the water-worn banks of rivers and road-cuttings, there are found innumerable flesh-red dykes, severally interpenetrating both the younger and older granites, and even the complexes of Takanuki and Gozaisho, and it is very remarkable to observe that wherever a granite occurs it is usually accompanied by this dyke rock.

No solid rock could withstand exposure to such powerful external agencies as the alternate frost of winter and heat of summer, which are excessive in, and very characteristic of, the climate of some parts of Japan as may be witnessed in the costumes of the people in the half-yearly exchange from a cold-temperate to a tropic fashion. All the rocks of the Abukuma plateau, especially the granites of coarse texture, are, therefore, soon reduced to an incoherent mass after new excavations even within the short interval of a few years. This necessitates incessant repair of roads, in order to keep them in tolerably good condition. Among such crumbling debris, the red pegmatophyritic dykes, in virtue of their solidity, escape the general disintegration, and stand up in bold relief in various directions crossing rivers and slopes of hills, and giving thereby a peculiar character to the scenery, when seen from a distance.

Guided by prudence, the people of the district use only this dyke-rock for macadamizing durable roads to which it affords a firm skeleton

and solidity. It would be superfluous to cite every occurrence of the dykes, since they are met with all the way through and in any part of this region, like Jacks at every street corner. A large series of exposures of the dykes under their least equivocal and most characteristic conditions of occurrence may be studied on the ascent from Nogami (Tamano-yu cold bath) to Chikenjō, Naraha gōri, for a distance of 8 km. This profile is very instructive, as there are found in it the often-mentioned two types of granite, one penetrating the other, and both passing imperceptibly into gneissose modifications, to which the name "*Iwaki gneiss*" has been already given. Through these granites, the *aplitic, pegmatophyritic*[1] *dykes*, the granophyre of Rosenbusch, make their way usually at low angles, and strike with the main axis (N 10 E) of the mountain.

These in turn are cut at very steep angles by a number of *diorite-porphyrite* dykes[2]. Since the filling up of the red dykes (Peg.), the country-rocks have undergone considerable tectonic disturbances to which is due the formation of parallel fissures (Fig. 2, Pl. XXIV). Different parts have then been shifted one after another, causing a continuous band of the dykes to appear like a set of stairs, and some of these clefts have been subsequently filled up with the igneous magma, which we now find in the shape of the black *diorite-porphyrite dykes*, as may be clearly understood from Figs. 2 and 3, Pl. XXIV. From what has been said, there is not the slightest doubt as to the younger age of the diorite-porphyrite, and its formation may perhaps have been at the time, when the crust in this quarter had suffered the last orogenetic movement, in which state it has re-

1 K. A. Lossen, *Vergleichende Studien über die Gesteine des Spiemonts und des Bosenbergs bei St. Wendel und verwandte benachbarte Eruptivtypen aus der Zeit des Rothliegenden*, Jahrb. d. Königl. preuss. geol. Landesanstalt für 1889, p. 270.

2 I wish to substitute the word *diorite-porphyrite* for lamprophyre in Figs. 2 and 3, Pl. XXIV.

mained since without any marked terrestrial disturbance. The black dykes are surely of post-archæan age.

Deferring details about the diorite-porphyrite to subsequent pages, I shall first speak of the material of the *pegmatophyritic dykes*. It is flesh-red and compact, breaking into polygonal blocks with sharp edges. Under the microscope it is very simple, as in its macroscopic aspect, but it shows a very instructive structure. The main mass is made up of nothing but quartz and orthoclase, regularly intergrown and showing a hieroglyphic or *à la grec* form. The only other ingredient, that is visible under the microscope, is a skeleton-like magnetite which is transformed at the margins into brown sesquioxide to which is largely due the reddish tint of the rock. The quartz and feldspar are in about equal quantities ; consequently it is difficult to decide which of them should be considered as the main mass. The latter is for the greater part kaolinized and dirty, while the fresh quartz is charged with swarms of liquid-inclusions.

The pegmatophyritic dykes occur, as has been already stated, in regular bands of uniform but moderate breadth, traceable for considerable distances. Apophyses have so far not been observed. Such being the condition in which the pegmatophyre occurs, I felt considerable diffidence in deciding as to its origin, whether, that is, it is a primary secretion after the manner of a miarolitic mass, or a filling up of cefts by lateral secretion, or lastly, an injected magma from the earth's interior, solidified in the present form. The last supposition seems to be the most probable, as the rock traverses indifferently all the varieties of granite, and even those of amphibolite.

The macroscopic development of the preceding is, to speak morphologically, nothing but pegmatite dykes, of which we have opportunities to meet with in

as large a number as the pegmatophyre dykes. Pegmatites are usually considered as an accidental, mineral aggregate, deposited from solution, by lateral secretion. If we view our pegmatite from this stand-point, its formation must be ascribed to an origin entirely different from that of the pegmatophyre dykes, in spite of close resemblance in their mode of occurrence, structure, and mineralogical composition.

My trip to the Abukuma district had for its scope to establish, if possible, the stratigraphical sequence of archæan rocks, the study of which has been long neglected by us, and which no one had attempted to follow in detail. Keeping always in my mind this important question, I had no time to avail myself of opportunities to make observations on dykes in general, and I am at present not able to say anything definite about the *relation of the pegmatite and pegmatophyre dykes.* At the time I simply considered them to be all of one and the same origin, which in reality cannot be the case!

The true *pegmatite* may be best studied at Ishikawa-yama, 2 km. north of Ishikawa, where Kochibe had found a crystal of beryl in the newly exposed dyke on the road-side. Large orthoclase, twinned on the Baveno type, and equally large and well-shaped, grey quartz, pegmatically intergrown with the former, together with biotite and muscovite, form the materials of the coarse dykes. Beautiful dykes of graphic granite with biotite may also be observed at Gomisawa, 12 km. east of Ono-niimachi. Microcline seems to form an important part among their components. These and many other dykes, of which there are ample variety, require more extended researches than I had time to institute.

B. *Dykes of Augite-dioritic Lamprophyres.*

A dyke of about 2 m., cutting through hornblende-granite, is found in Nishiyama (Ogura), on the way to Tanagura. It is a

compact, dark-greyish rock in which are porphyritically imbedded crystals of hornblende and augite (3 mm.). No other components are visible to the naked eye. Under the microscope it proves to be pilotaxitic, consisting of lath-shaped plagioclase, needles of hornblende, and magnetite, with scanty remains of some colourless basis, which fill up the interstices of the crystalline ingredients.

The phenocrysts are plagioclase, hornblende, augite, and a zeolitic mineral; the first is long rectangular or square, occurs in simple crystals, or in simple twins, all extinguishing in oblique directions at more than 30.° In spite of the simplicity of the crystals and the scarcity of twins, the feldspar may be looked upon as a basic plagioclase. Zonings of the plagioclase are well developed, the central part being often hollow, and partially filled up with a chloritic aggregate; the peripheral zone is fresh and glassy. The hornblende is greenish-brown; its forms are never perfect, but eaten away by magmatic corrosive action, and the crystals are in consequence encircled by an aggregate of opacite and needles of augite. These marginal masses are prolonged into long "tails," just as hornblende is in some porphyrites. Its pleochroism is quite pronounced. Twins of common type are discernible *only in that shape which has been formerly considered as anomalous twins whose plane of contact was said to be the prism* $\infty P2$ *(120).*[1] The augite is rare, its habitus is andesitic, consequently its basal section is approximately hexagonal, being bounded by the predominating faces of pinacoids, truncated at the four corners by prismatic faces, and its colour is light-yellow and non-pleochroic. Biotite and olivine are not to be seen in the specimens hitherto examined. This dyke-rock seems to have a close resemblance to the *comptonitic modification of the dioritic lamprophyre.*

1 Becke; Tschermak's Mineralog. und petrogr. Mitth. Bd. IV, p. 365.

Near Harimichi, south-east of Fukushima, Kochibe has found many dykes of a dark-green, fine-granular diabase in granite, containing grains of olivine.[1] This may probably belong to the same class of rocks as the present one.

A similar dyke may be seen in a vertical cleft of about 2 m. within a nodular hornblende-granite at the boundary of Nakagura and Nakatani (L P in Profile F-F, Pl. XXV).

C. *Dykes of Diorite-Porphyrites.*

There are many peculiar dyke-rocks whose mutual relation to each other, and to the country rocks are but imperfectly known. I can give here only a preliminary notice of them, deferring their microscopic detail to another occasion. Their mineralogical composition and structural form seem to deviate so greatly from normal *dyke rocks, that I feel considerable diffidence* in placing them in any of the known class of lamprophyres. The dyke materials show great variations within narrow limits. From a compact, grey hornstone-porphyry to a light-coloured, coarse crystalline diorite-porphyrite, they vary through a number of intermediate forms. Some of them appear dark and fine granular, others are aphanitic; while a third modification is medium-granular with black hornblende-crystals porphyritically imbedded within the greyish general mass. In short, they seem to have nothing in common to them, but in reality they are offsprings from a common stock under deceptive appearances.

1) *The compact variety* possesses the aspect of a *hornstone-porphyry*, with sporadic crystals of feldspar as a porphyritic component; the general mass is grey, and is splintery with a conchoidal

1 Harada, *Die japanischen Inseln*, p. 76.

fracture. Under the microscope nearly the half of the whole bulk is seen occupied by granophyric bundles which consist of fibrous feldspar and quartz arranged in a divergent-radial manner around a feldspar-crystal, so as to form a spherulite. Between crossed nicols the spherulite is divided into imperfect sectors which sweep along one after another as the section is rotated on the stage. A few plates of hornblende and lamellæ of muscovite are irregularly intermixed with the granophyric mass, from which it may be inferred that the spherulitic bundles came into existence after the crystallization of the bi-silicates. The formation of these bundles is probably the effect of an unequal cooling, or they may have been formed secondarily in a manner somewhat similar to that of devitrification by molecular rearrangement and differentiation of an unindividualized mass.[1] The remainder of the rock consists of a cryptocrystalline aggregate of quartz and feldspar, muscovite and green hornblende; most of the colourless components becoming visible only on applying crossed nicols. Copper pyrite is present.

2) *The dark and fine-granular dyke rock* has a few feldspar-crystals as a porphyritic element. No other minerals are discernible by the naked eye. Under the microscope the porphyritic feldspar is found beautifully zoned with different optical orientations in the centre and the periphery, having an extinction-angle of more than 20° with the twinning sutures; the decomposition begins in some from the core, whereas in others just the reverse happens. The minerals of the second generation are the bluish-green, fibrous hornblende, and zonally structured, long-rectangular or square-shaped feldspar; while the general mass is made up of needles of hornblende and lamellæ of tea-green biotite, lath-shaped feldspar, and grains of quartz. The structure is holocrystalline-porphyritic. Accessories are apatite, octa-

1 *Vide ante* p. 235.

hedra of magnetite, and a little epidote.

Through the preponderance of feldspar of the second generation, the rock becomes dioritic in appearance with somewhat large crystals of fibrous hornblende as porphyritic crystals often arranged in stellar aggregates. Some of the fibrous amphibole contains cores of *augite*, from which it may be inferred that the hornblende of uralitic habitus has been derived from the augite.

3) *The third modification* is black and fine-granular, and a dark magnesian bisilicate glitters through it by reflected light. Examined with high powers, it is a panidiomorphic-crystalline aggregate of lath-shaped feldspar, and prismatic hornblende, together with biotite and epidote. The feldspar is simple-twinned, rarely polysynthetic, and more or less kaolinized and dirty, being full of muscovite, with the secondary epidote at the centre; zonings are rarely developed. The hornblende is prismatic in habitus with the clinopinacoid present, so far as may be judged from the outlines of imperfect basal sections. It is pleochroic; $\mathfrak{c}$ = dark-brown with a slight tinge of violet, $\mathfrak{b}$ = brown, $\mathfrak{a}$ = light-yellow; absorption, $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$. Forms of the hornblende are never perfect, but ragged and tattered, as if it were, the resorption-residue of larger individuals. This supposition is, moreover, strengthened by a beautiful emerald-green colouring of the peripheral portion which is materially connected with the brown core; the former has surely resulted from alteration of the original amphibole. At first sight, the hornblende appears like augite, for which it may be easily taken. It seems to me that the present amphibole is likely to be one of the sodium-bearing varieties, as otherwise the formation of the bluish-green margins can not be explained.

A dirty green biotite is irregularly scattered through the whole mass, and the dark colour of the rock is due mainly to the presence of this component. Titaniferous iron is sparingly present with highly

refracting margins of titanite. Zircon with well-finished forms is also observed. The structure is more or less porphyritic. The part in direct contact with the cheek of granite is typically porphyritic, with feldspar, hornblende, and biotite as large components; while the rest is a crypto-crystalline aggregate of grains of feldspar and quartz, and also foliæ of biotite, making the ground mass of a beautiful fluid-like structure, seen in the bending of streams, and bands of mica around the larger feldspar-crystals.

4) *The coarse porphyritic modification.*—This differs entirely from all the preceding rocks in its external appearance, so that any confounding of this with the other varieties is impossible. It is a typically porphyritic rock with large, rectangular or broad-tabular feldspar (3 mm.) imbedded within the greyish ground-mass. The feldspar is zonally structured with differentiated optical orientations in each zone. Some crystals are simple; a few are coarsely polysynthetic with oblique extinctions of about 14° with the suture-line, while about 23° with P/M on the brachypinacoid. Therefore, it corresponds to the mixture of $ab_1 an_2$ of the labradorite series.

Minerals of the second generation are also discernible by the naked eye, if carefully examined. They are long-rectangular, polysynthetic plagioclase, devoid of zonal shells, and a greenish prismatic hornblende with combination of the pyramid, prism, and brachypinacoid. The hornblende is greenish-brown or bluish-green, and pleochroic. A dirty-green biotite is found with sagenitic rutiles in apparently fresh lamellæ.

The general mass in which the components of the earlier generations are found, consists of a crypto-crystalline aggregate of grains of feldspar and quartz, and also shreds of a green biotite. Accessories are rounded apatite, and titaniferous iron with the margins of leucoxene.

IX. Summary.

The general results I have arrived at by my study of the archæan formation of the Abukuma plateau may be summarized as follows :—

This archæan plateau constitutes a portion of the ecto-peripheral zone of the North Japan *garland*,[1] and is separated from the backbone of the island by the longitudinal valleys of the Abukuma-gawa and Kuji-gawa, while on the east it is bordered by the Pacific sea-board. The south end of this archæan zone has been the subject of one[2] of my former papers. The present one is the result of study made in the northern prolongation of the same belt, *i.e.*, the Abukuma plateau.

The archæan rocks of this region are primarily separable into a lower division, the Laurentian, and an upper division which again may be subdivided into two well-recognizable, leading groups, the Gozaisho and the Takanuki series.

The *Laurentian* is mainly composed of rocks of the granitic, syenitic, and dioritic types of mineralogical composition, and panidiomorphic-hypidiomorphic granular structure. These granitic-granular rocks show in places different degrees of schistosity, depending upon the circumstances under which they have been formed. Accordingly we have a number of foliated granites which may be conveniently brought together under the following heads, viz., 1) imperfectly schistose amphibole-granite, 2) schistose amphibole-granite, and, lastly, 3) schistose epidote-granite. The young biotite-granite, though less extensively developed than the other, has also equivalent modifications.

1 The late Melchior Neumayr, when speaking of volcanic islands, said: *Vom Feuerland an zieht sich eine Riesenkette gewaltiger Vulkane nach Norden, bis Alaska, wo dann jene eigentümliche Bildung geschwungener Vulkanreihen, meist auf Inseln gelegen, beginnt, welche (Festoninseln) man mit herabhängenden Blumengewinden verglichen hat. Erdgeschichte*, I Band.

2 See p. 198.

These pathological varieties, so to speak, which go by the current name of gneiss-granite or granite-gneiss, though very improperly, are, no doubt, mainly dynamo-metamorphic products. Microscopic analyses give at any time sufficient proofs of their having been affected in the way indicated. My own detailed study of them shows that the first inducement to the schistosity of granites is to be found in the slight shifting in position of the ferro-magnesian silicates, and in the commencement of granulation in the solid quartz. In a more advanced stage of schistosity as in 2), ordinary schistose granite, all essential components have been compressed into deformed bodies; the once evenly lamellar biotite altered into flexuous and wrinkled lamellæ with bird's-eye-maple shimmer; the hornblende no longer of a prismatic form; and the quartz and hornblende rolled out and grained and compacted into one mass with a feldspar centre zoned by the grains of quartz, thus simulating the so-called centric structure by migration of the granular quartzes. In the last phase of transformation as in 3), the schistose epidote-granite, the hornblende has disappeared entirely, being replaced by a mass of epidote and magnetite. The biotite is bent and frayed out at the margins. Heterogeneous aggregates, consisting of epidote, magnetite, and chloritic matters, form wandering zones. The feldspar, the most enduring mineral, escapes the general disintegration and granulation, excepting in its peripheral portion, where the crystal is crushed, producing the cataclastic structure. In spite of the solidity of quartz, this has always been the first to yield to pressure.

The cause of the schistosity is undoubtedly dynamo-metamorphic. Extensive rendings and foldings have taken place in the Abukuma plateau only at the marginal zones, while the central height has remained quite intact. By the orogenetic, differential movement thus produced, the east and west side of the plateau have been thrown

down to a lower level, along the meridional line of dislocation. Consequently the granulated and compressed varieties—the schistose granites—are confined to the above-mentioned tectonic lines, one along the Pacific sea-board, and the other along the Abukuma valley, as may be clearly understood from the diagram, page 232.

I have repeatedly spoken of the young and old granites which are by no means easily distinguishable from one another. They occur in such a confused manner as to try the patience of even careful observers; and many have entirely ignored the heterogeneous origin of the two kinds of massive rocks. The best exposure, illustrative of the mode of occurrence of the younger biotite and older hornblende granite may be found between Ishikawa-yama and Shimo-Kawabe, where the two appear successively between the line of fault after the manner of ruin-marbles (Fig. 5, Pl. XXIV), and moreover assume at times a schistose structure. In this exposure, it is clear that one is the dyke-rock to the other, but the granites being developed in almost equal masses it is not easy to say which is the country-rock and which the intruding one. Another very illustrative profile is shown in Fig. 1, Pl. XXIV, in which such complicated modes of occurrence of the granites are to be seen that their mutual relations can not be easily determined.

Judging from the wide distribution of the hornblende-granite, it seems to form the general foundation of the Abukuma plateau, upon which are built up all the later formations. If this be the case, then the hornblende-granite in the first section must be the country-rock through which the biotite-granite made its irruptions at several points, the older one being itself already in the solid state. In the second section the same cannot be said; for the two granites intermingle with one another in such a manner as to lead one almost to suppose that the hornblende-bearing variety must have been in a more or less plastic

condition at the same time as the other. It is thus a matter of considerable difficulty to decide which is the earlier granite.

When speaking of the line of section at Shimo-Kawabe (p. 271), it has been already shown that the brownish, granulitic gneiss of the Lower Takanuki series, accompanied by a micaceous schist with plenty of garnet, has been so disturbed in various ways and at numerous points by the intrusion of biotite-granite, as to make one believe that the gneiss-complex has been broken up and cemented subsequently together by the matrix of that plutonic rock. Generally speaking, the biotite-granite occurs only in the form of apophyses or of bosses within other complexes. On the other hand, the hornblendic variety seems to be present in extensive masses, disturbing all the complexes formed prior to the period of the Gozaisho series, in such a manner as if the whole Takanuki rocks had been swimming on that magma. The last-mentioned series, in all observed cases, is geologically separated from the Gozaisho rocks by the intervention of masses of hornblende-granite.

The biotite-granite, as I have already said, intersects the Takanuki series at numerous points, forming sporadic masses and irregularly ramifying dykes; the relation of the hornblendic variety to the same complex is, however, somewhat different. Near the contact the Laurentian granite holds as enclosures sharply angular, sub-angular, or somewhat rounded blocks of mica-schists and amphibolites of the Takanuki series. This is well seen on the Hanatate pass (A-B, Pl. XXV). The schistose modification of the same has likewise foreign enclosures of the Takanuki rocks, as more or less attenuated bands drawn out parallel to the foliation of the hornblende-granite and confused with it (Fig. 5, Pl. XXIV).

These facts, taken in connection with the prevailing shattered character of the Gozaisho, and of the Takanuki strata in particular, at

their contact with the Laurentian rocks, leave no room for doubt but that these inclusions are detached portions of the overlying formations, which, in a firm and brittle condition, have become immersed in the underlying viscid magma, which subsequently crystallized out as the Laurentian gneiss and granite. This mode of foliation of the granites *(plastic deformation)* seems to have been produced by differential pressures upon the thickly viscid magma, inducing a flow in the mass, similar to that endogenous growth of a volcano by *Nachschub*, experimentally observed by Reyer. To this flow is ascribable both the schistosity of certain foliated granites, and the parallel arrangement of enclosures of foreign rocks imbedded in it, as in the Rainy Lake region.[1] It must be expressly remarked that there is another process which leads to the formation of foliation, quite distinct from that just mentioned, which may be termed that of *solid deformation*, since the schistosity is in this case brought about by internal granulation of the component-minerals. Foliated granites, which occupy extensive area in the plateau, owe their structure to the latter action.

The upper archæan is represented by bedded formations, in which can be recognized at least two leading groups.

One of them is the *Takanuki series* which is again divisible into the lower acid, and the upper basic member. *a*) The former rests directly upon the Laurentian, and its petrographical elements are gneiss-mica schist, two-mica schist, garnet-biotite schist, and hornblende-biotite schist, which together make up the considerable thickness of 5,000 metres. All these rock-varieties have in common a tabular form with the plane-parallel structure, and their transverse sections show the interbanding of black-mica zones with light-greyish quartz-feldspar layers (photograph, figure 2, Pl. XXVII).

1 Andrew C. Lawson, *On the Geology of the Rainy Lake Region*, p. 131. *et seq.*

Where biotite occurs in only small quantities, they approach both in appearance and composition to a granulite. Feldspars, both monoclinic and triclinic, usually make only a small fraction of the whole rock which, in consequence not infrequently passes locally into a typical mica-schist. This complex seems to correspond with Harada's *Rioké schiefer*,[1] so named from the locality of Rioké, Sūchi gōri, in the province of Tōtōmi, where the rocks were collected for the first time. Harada seems to have given them that name simply with the petrographic object of covering with it various schists of his gneiss system, found near the village of Rioké, without assigning to them any special horizon in his stratigraphic scheme.

β) The Upper Takanuki complex embraces multifarious alternations of 1) the titanite-amphibole schists and 2), the gneiss-mica schists. The first are black, highly crystalline schists with the plane-parallel structure, whose transverse section shows interbanded, thin, light-coloured zones, recurring hundreds of times even in a small chip. They are perfectly schistose, cleaving easily into papery slabs; and as their texture is not so compact as that of the underlying mica schists, they readily fall into a bluish-black ashy powder on their weathered surface. These black, fissile schists are peculiarly characterized by the presence of titanite which is found in those forms which resemble rolls of butter *(weckenförmig)*, and with sometimes a black, formless mass in their centre, which is probably of a titaniferous iron. Another very interesting component is the salite which almost exclusively makes up the stuff of the light-green zones. Biotite is present, but it never takes an important part in the composition of the rock; still it should be considered as a characteristic ingredient, since it is entirely wanting in the series text above it. It may be readily recognized on the plane of schistosity by its gold-yellow, glittering lustre. We name these

1 *Loc. cit.* p. 43.

titanite-bearing rocks in the field the biotite-amphibolites in order to discriminate them from other kindred varieties. The biotite-amphibole gneiss occurs usually in lenticular masses. Those of the other category (gneiss-mica schists) show the following modifications, namely, gneiss-mica schist, two-mica schist, garnet-biotite schist, and also hornblende-biotite schist. The whole complex, consisting of the above-mentioned rocks, attains a considerable thickness, as seen in the exposure between the hilly stretches from Nakagura to Sōri (E-F, Pl. XXV), where this Upper Takanuki was found to have the thickness of 5,500 metres.

The voluminous green mass of the *Gozaisho series* is well exposed along the banks of the Samé-gawa whose river course runs nearly at right angles to the strike of the whole complex. Its basal member lies in a somewhat elevated portion of the plateau on the west, while in the eastern half of the section, towards the tertiary hills of Kadōno, the younger series occurs, with a thickness which I venture to estimate as probably not less than 10,000 metres.

The uppermost rock of this series is a greenish, rather massive schist, cropping out along the banks in a vertical position but with a slight inclination towards the east. It has the aspect of a clastic rock, and is like a hardened deposit of volcanic ashes. This is followed to the west by alternate bands of green schists and quartz rocks, intruded into at times by a hornblende-granite. A black mica-schist accompanies these green schists. They gradually disappear, to give place at last to a black, crystalline, hornblende schist which occupies the basal portion. When we compare the extreme members of these schists, side by side, they seem at first sight to have nothing in common with each other, but on close examination in the field they are seen to form a lithological continuity and a harmonious whole. These green, fissile rocks have much the same appearance as the clasto-pyroxenites

of my Mikabu series, which form the basement of the palæozoic group of Japan.

Sometimes they bear a striking resemblance to the chlorite schists of my Sambagawan series,[1] which lies directly below the Mikabu complex. The question concerning the age of the Sambagawan series involves serious difficulties. When the results of my studies on the schists of Chichibu[1] were made public in 1888, I expressly remarked that it is by no means safe to give the Sambagawan series a final resting place in the archæan group, without extended researches. In spite of my warning against such a hasty conclusion, Dr. Harada[2] assigned its place to the Upper archæan, as had been done before him by Dr. E. Naumann. I do not as yet find any positive argument that supports its archæan position, as no additional light has since been thrown on the stratigraphical situation of the Sambagawan series. The relation of the Gozaisho series to that of the Sambagawan is unfortunately not very clear, and we must wait for some time to come to see the final solution of the problem, whether the two are geological equivalents, or whether they succeed each other in point of time.

I take here the opportunity of expressing my thanks to Professor Edward Divers and Director Dairoku Kikuchi for their kindness in assisting me in various ways in the revision of the proof sheets of this paper.

1 This Journal, vol. II.

2 *Loc. cit.* p. 49.

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PLATE XXII.

Plate XXII.

Topographical map, recently published by the Geological Survey of Japan, representing a portion of the extensive plateau of Abukuma between Tanagura and Taira. It covers a portion of the province of Hitachi, and also that of Iwaki. The red lines indicate the positions of the line of section, given separately in Plates XXIV and XXV, with corresponding letters.

A MAP OF A PORTION
OF THE
ABUKUMA PLATEU.
(Between Tanagura and Taira)
N.B. The lines of Section are drawn thick and full.
Sh. Shima (Lower.)
Nu. Naka (Middle.)
Ka. Kami (Upper.)
Mi. Minami (South.)
Hi. Higashi (East.)
Ni. Nishi (West.)
d. Dake (Mount.)
y. Yama (Mountain.)
Pacific Ocean
ISHIKAWA
IWASA
NI-SHIRAKAWA
HI-SHIRAKAWA
IWAKI
KIKUTA
SHIRAKAWA
HITACHI
IWAKI
IWASAKI
TAIRA
Takayama
Nagaitôge
Atagoyama
Shibayama
Amefuri y.
Daibutsuyama
Ôtsuppei
Hamakura d.
Akaidake
Ôtakisan
Futatsuishi
Sandaimyôjin y.
Takakura y.
Yunotake
Mikabuyama
Sumakitôge
Goraisho y.
Kokabu y.
Nijibu y.
Ogawa y.
Butsugu y.
Ôshôdan
Yatarôy.
Koenyashiki
Tengunomine
Kanaronoy.
Takabo y.
Kurakake y.
Sankonomuro y.
Toizbiyama
Fujiyama
Hirakata
Kubota
Onakama
Tanagura
Yamato
Kumihino
Negishi
Ôtaira
Shibukawa
Kokonetsuyama
Hoboy.
Shirobokka r.
Sakaibashi
Tokyo
Yokohama
Kamakura
Odawara
Hakone
Fuji
Tokaido
Nakasendô
Ôshu Kaidô
Sagami
Musashi
Kôzuke
Shimotsuke
Iwaki
Iwasaki
Kitakami
Abukuma
Tamagawa
Sakawa
Kuzuryu
Tonegawa
Arakawa
Sumidagawa
Tamagawa
Tokyo
Yokohama
Kamakura
Odawara
Hakone
Fuji
Tokaido
Nakasendô
Ôshu Kaidô
Sagami
Musashi
Kôzuke
Shimotsuke
Iwaki
Iwasaki
Kitakami
Abukuma
Tamagawa
Sakawa
Kuzuryu
Tonegawa
Arakawa
Sumidagawa
Tamagawa
Scale 1 Millim.
Scale 1 Millim.

PLATE XXIII.

Plate XXIII.

Fig. 1,—illustrates the point of contact of two granites, the lower half representing the intruding, young (biotite-) granite, the upper half, the intruded, older (hornblende-) granite. Feldspar and quartz at their contact are variously fissured, and the lines of fracture thus produced run approximately parallel with each other. (See p. 242.)

Fig. 2.—A bluish-green hornblende, forming an essential ingredient of granite. (See p. 227.)

Fig. 3,—shows a green hornblende with the imbedded grains of salite, each having different optical orientations. (See p. 255.)

Fig. 4.—Reactionary rim consisting of the grains and needles of epidote around a decomposed biotite at the contact with feldspar. (See ps. 234 and 238.)

Figs. 5 and 6,—represent peculiar forms of titanite, resembling rolls of butter, with opaque, formless masses of titaniferous iron. (See p. 256.)

Fig. 7.—A somewhat large, allotriomorphic hornblende, enclosing a number of equally allotriomorphic crystals of plagioclase, oriented in diverse directions. (See p. 227.)

Fig. 8.—Black dioritic patches of various sizes enclosed in hornblende-granite, as if a dioritic scum had floated on a granitic paste, and then been torn asunder by some movement in a semi-fluid magma. These patches are only a portion of the same granitic magma, slightly different in chemical composition. (See p. 217.)

Fig. 9,—shows many stiff, disjointed needles of ? sillimanite. (See p. 220.)

Fig. 10.—Crystalloids and grains of hornblende, enclosed by a feldspar. (243.)

Fig. 11.—Section of the Nakagura valley, showing the heterogeneous nature of schistose granite and the Upper Takanuki complex. (See p. 215.)

Fig. 12.—Salite, a characteristic component of titanite-amphibolites, with black streaks regularly arranged parallel with the c-axis. (See p. 254.)

1

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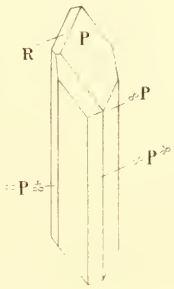

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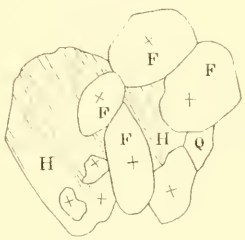

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Dark Dioritic Granite

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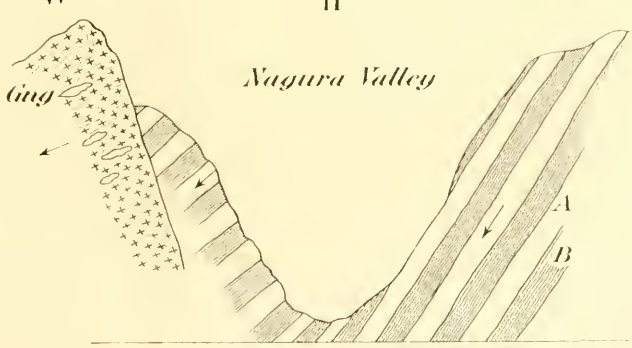


Strike N. 55 E.

12

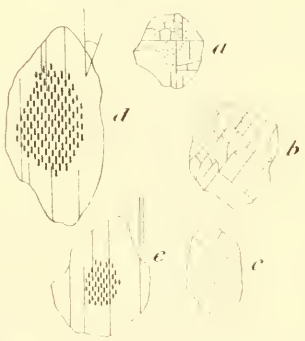


PLATE XXIV.

Plate XXIV.

Fig. 1.—Section from Serigasawa to Miharu, the latter being the well-known town in the Abukuma plateau. It exhibits the complicated mode of arrangement of granites. (See p. 219.)

gnBG,—schistose biotite-granite;
BG,—biotite-granite;
gnG,—schistose hornblende-granite.

Fig. 2 and 3.—Cuttings along the newly opened road west of Tamano-yu, Naraha gōri, Iwaki, showing the relations of granites and dyke-rocks. (See p. 276.)

HG,—hornblende-granite;
BG,—biotite-granite;
Peg,—pegmatophyre-dykes;
Lamprophyre,—diorite-porphyrite.

Fig. 4.—Section J-K, from Kami-Matsukawa in north-easterly direction to the district-boundary of Ishikawa and Shirakawa, illustrating very clearly the relations of the Takanuki series, granites, and serpentine.

gnG,—schistose hornblende-granite;
HG,—hornblende-granite;
BG,—biotite-granite;
UT,—Upper Takanuki;
LT,—Lower Takanuki;
S,—serpentine.

Fig. 5.—Section near Shimo-Kawabe, showing the relation of schistose hornblende-granite and fleams of the Takanuki gneiss. The whole is traversed by a pegmatitic dyke. (See p. 218.)

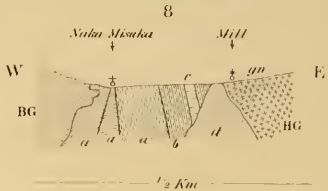
Fig. 6.—Cutting between Tonda and Higashino, exhibiting black, attenuated patches of the dioritic composition within hornblende-granite, which arise from chemical differentiation of its granitic magma. (See p. 216.)

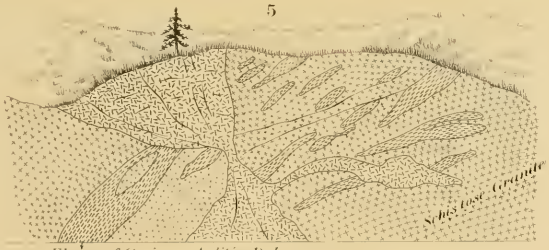
Fig. 7.—Section near Ōtsuka, as exposed on road side, bringing to view a graduatransition of hornblende-granite to its schistose variety within the amphibolite series of the Upper Takanuki. (See p. 214.)

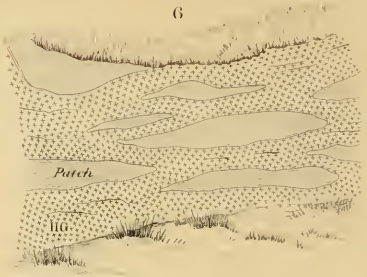
A,—gneiss-mica-schist;
gnG,—schistose-granite;
B,—titanite-amphibolite;
HG,—normal hornblende-granite.

Fig. 8.—Small belt of the Gozaisho rocks pinched in between granites. (See p. 212.)

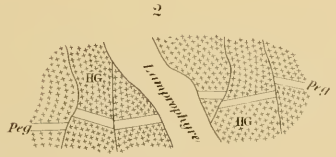
BG,—biotite-granite;
b,—salite-hornblende-schist;
d,—amphibole-picrite;
gn,—schistose hornblende-granite.
a,—epidote-amphibole slate;
c,—chloritoid-quartz-schist;
HG,—hornblende-granite;

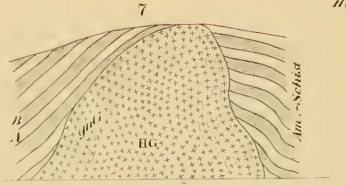




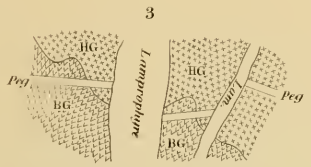


Exposure between Tonda and Higashino, Higashi-Shirakawa Gôri.





Exposure at Oksuka



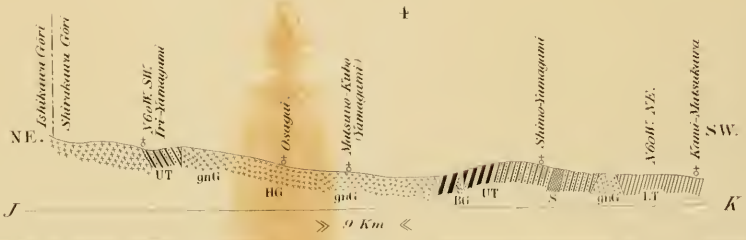


PLATE XXV.

Plate XXV.

In this Plate, an attempt is made to illustrate by means of four sections the general geological succession of the Laurentian, Takanuki, and Gozaisho divisions of the Abukuma Archæan, together with the dykes of lamprophyre and pegmatophyre. The positions of the line of section are indicated by thick lines, with corresponding letters on the map, in Plate XXII.

Section A-B, from Hirakata on the Pacific sea-board through Nakayama to Kawakami in the Kuji valley. (See p. 202 *et seq.*)

Section C-D, is drawn westwards from Kadōno, 12 km. west of the city of Taira, across the ridge of Gozaisho, to the west of Takanuki. This is the best profile of the whole region. MG=BG, *i. e.*, biotite-granite. (See p. 204.)

Section G-H, from Ishikawa to Shimo-Kawabe on the right bank of the Abukuma. (See p. 216.)

Section E-F, from the small hamlet of Kami-Misaka (where a patch of the Gozaisho may be seen) to Ishikawa on the west. (See p. 212.)

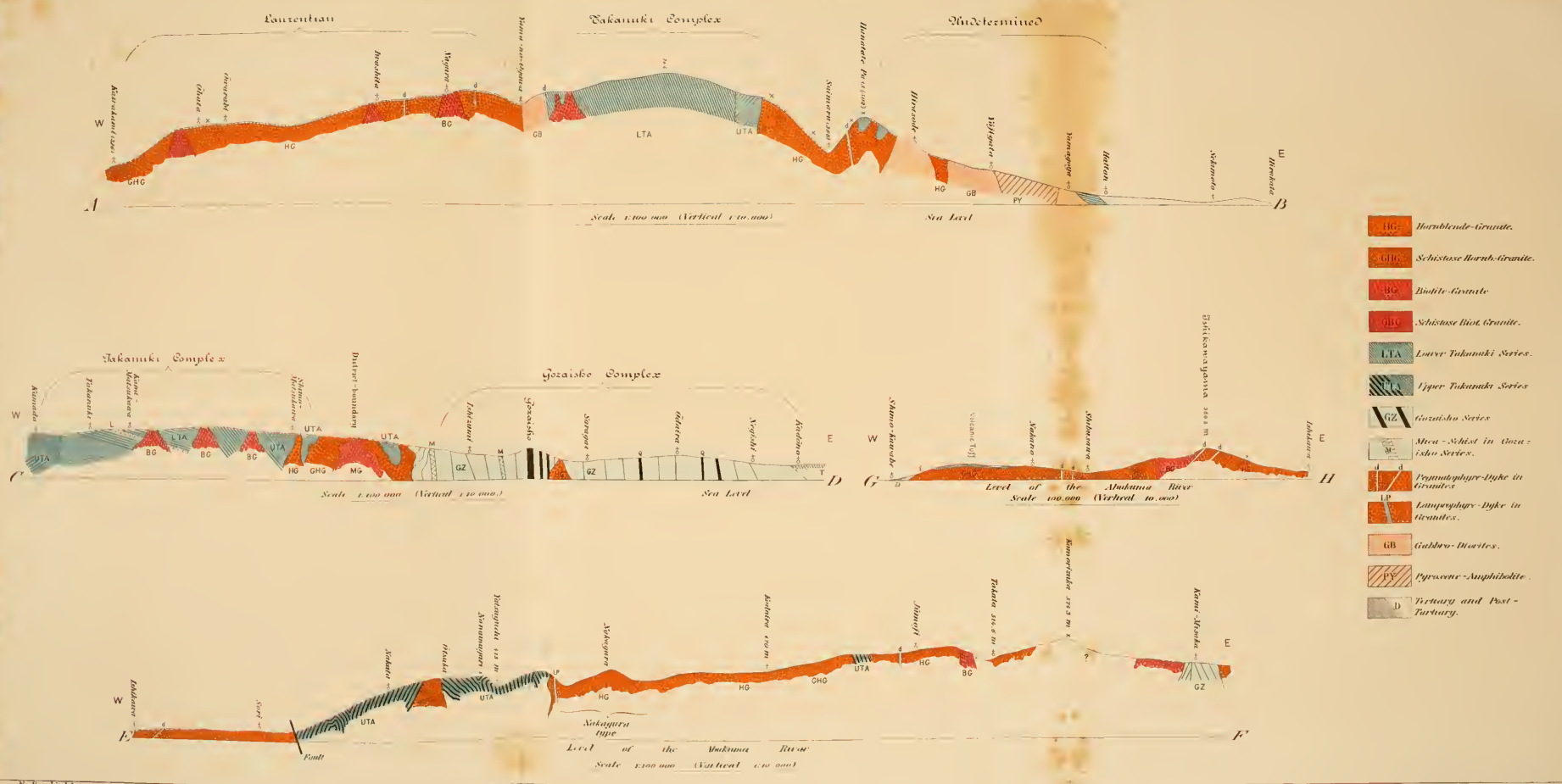

Laurentian
Takanuki Complex
Undetermined
Scale 1:100 000 (Vertical 1:10 000)
Sea Level
Takanuki Complex
Gozaisho Complex
Scale 1:100 000 (Vertical 1:10 000)
Sea Level
Level of the Abukuma River
Scale 100 000 (Vertical 10 000)
Level of the Abukuma River
Scale 1:100 000 (Vertical 1:10 000)
Hornblende-Granite.
Schistose Hornb-Granite.
Biotite-Granite
Schistose Biot. Granite.
Lower Takanuki Series.
Upper Takanuki Series
Gozaisho Series
Mica-Schist in Gozaisho Series.
Pegmatophyre-Dyke in Granites
Lamprophyre-Dyke in Granites.
Gabbro-Diorites.
Pyroxene-Amphibolite.
Tertiary and Post-Tertiary.

PLATE XXVI.

Plate XXVI.

In this Collotype Plate, an attempt is made to represent the general features of the most characteristic rock-sections, as they appear under the microscope. All give the magnification of 140 diameters.

Fig. 1,—represents the rock-section of garnet-chloritoid-quarz-schist, one of the members of the Gozaisho series. Colourless granules in the photograph is the aggregate of garnet, while the irregularly outlined, black patches are the plum-green lamellæ of chloritoid. The white ground consists of quartz. (See p. 270.)

Fig. 2,—shows a portion of the light-green band in titanite-salite-amphibolite. The crystalloids with a few cleavage-lines are the crystal-grains of salite, while at the lower margin of the figure we find a basal section of the same with its characteristic augite-cleavage. The white ground in the figure represents the aggregates of feldspar which is changed into a colourless, fine fibrous, confused mass, displaying highly chromatic, aggregate polarization-colours. The intact part of the feldspar appears in a sporadic manner within the micaceous mass which seems to be identical with pseudophite or saussurite. (See p. 253.)

Fig. 3,—shows sillimanite in confused aggregate, occurring in garnet-biotite-schist of the Takanuki series. (See p. 251.)

Fig. 4,—is the section of a typical titanite-biotite-amphibolite, in which are seen the bacillar amphibole, and round titanite, resembling rolls of butter, sometimes with clumps of titaniferous iron in the centre. Locality: Kamada near Takanuki. (See p. 252.)

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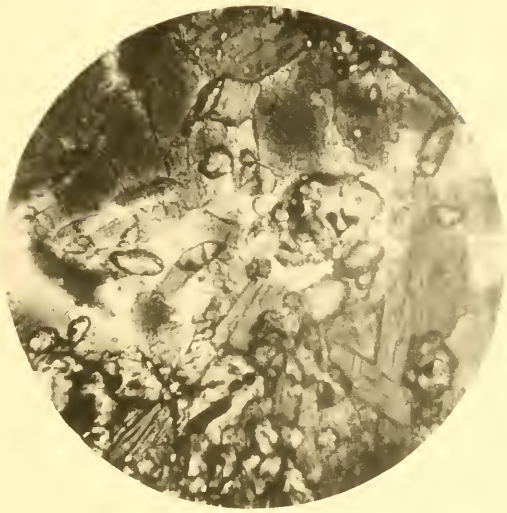

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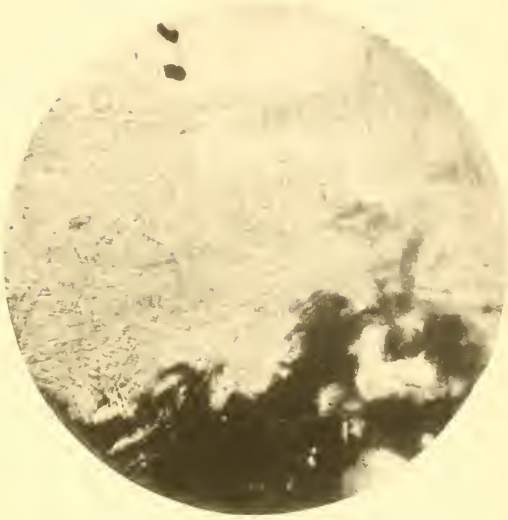

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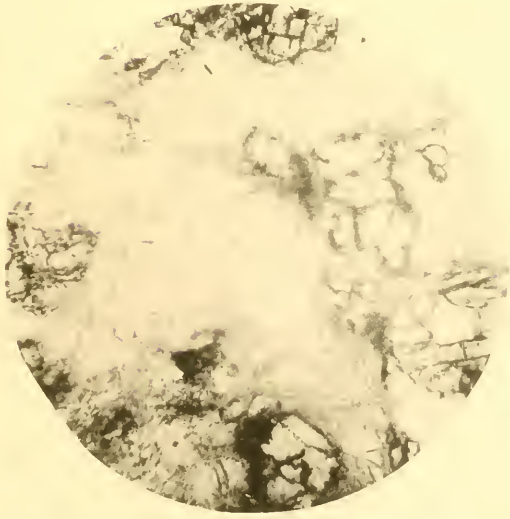

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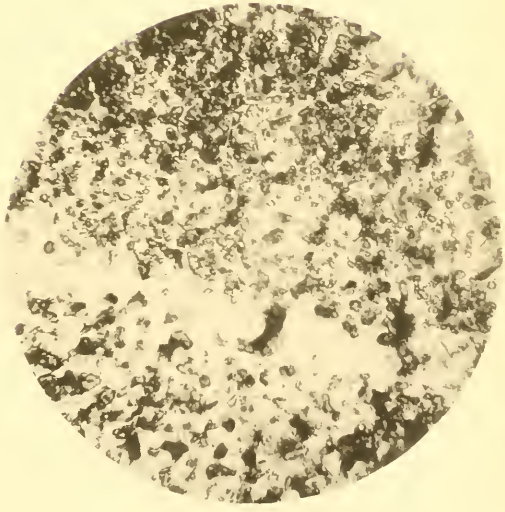


Collotype by K. OGAWA.

PLATE XXVII.

Plate XXVII.

This Plate represents the appearances of the polished surfaces of the Takanuki and Laurentian rocks, at right angles to the plane of schistosity, excepting Fig. 4.

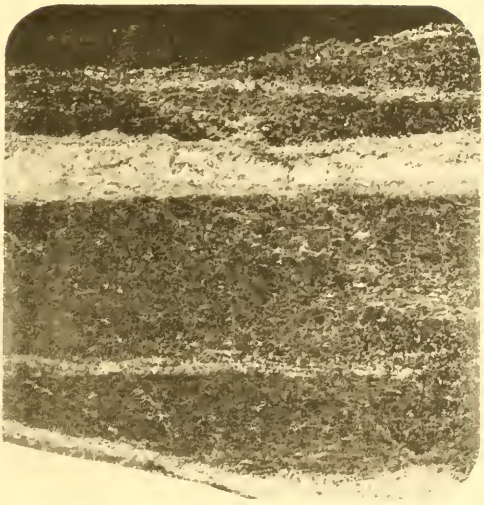
Fig. 1,—is the transvers esection of titanite-salite-amphibolite. The dark bands are mainly composed of a bacillar amphibole, alternating with the white bands of salite whose magnified section is represented in Fig. 2, Pl. XXVI. (See p. 258.)

Fig. 2,—shows the transverse section of a granulitic gneiss-mica-schist of the Takanuki series. Locality: Kamada near Takanuki. (See p. 248.)

Fig. 3,—shows also the transverse view of a schistose granite, from the Kawachi pass, Naraha gōri, Iwaki. (See p. 236.)

Fig. 4,—shows a view parallel to the schistose plane of a granite of a dioritic type of mineralogical composition, brought from Shimo-Matsukawa, on the banks of the Samé-gawa.

1



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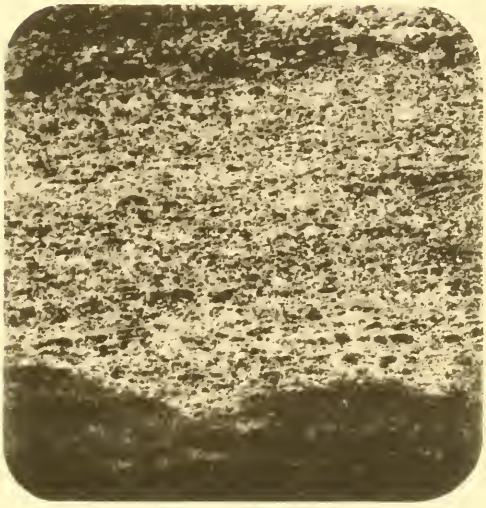

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Collotype by K. OGAWA.

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On the Cause of the Great Earthquake in Central Japan, 1891.

By

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With Plates XXVIII-XXXV.

Introductory.

CONTENTS.—Introductory. I. Dislocations. II. Geology and Topography of Mino and Owari. III. The Great Earthquake of the Mino-Owari Plain. IV. Various Views as to the Origin and Cause of the Earthquake. V. Relation of the Great Fault to the Recent Earthquake. VI. The Course of the Line of the Great Fault that caused the Earthquake. VII. Concluding Remarks.

Geologists have rarely enjoyed so good an opportunity as that afforded them by the convulsion in the Mino-Owari plain, of observing those great displacements of rocks called "*faults*," which may only be brought about in the course of ages. Only a very few cases have ever been recorded in the annals of earthquakes, of the formation of throws of strata accompanied by subterranean shocks.

Lyell mentions in his classical work, *Principles of Geology*, a case that occurred in New Zealand, in 1855. A tremendous earthquake was experienced there, by which, especially in the vicinity of Wellington, in North Island, a tract of land comprising 4,600 square miles is supposed to have been permanently upraised from 1 to 9 feet. The line of fault was distinctly observed in the sea-cliff, called Muka-Muka, where the uplifted older rocks abut upon the lower, Tertiary plain of Wairarapa; and the course of the fault was traceable inland to the extraordinary distance of about 90 miles, in approximately

north-south direction along the Remutaka Mountains.

Another well defined case is that of the ever memorable Calabrian earthquake of 1783. The southern extremity of the mainland of Lower Italy is chiefly composed of primeval rocks. Gneisses and granites occupy the greater part of the country, being partially covered by Miocene and Pliocene of the facies of Flysch. A great *peripheral* or *longitudinal fissure* is said by Suess,* to traverse the whole length of that part of the country called Calabria, and along this tectonic line, the fearful shocks of 1783 found their way, having for their destructive centre the city of Oppido. The seismic activity continued for some weeks, and the shocks spread north, south, and west, but very little towards the east, chiefly confining their motion to the fissured line of the fault. The maximum point of the convulsive attack was transferred from one place to another through Soriano and Polia up to Girifalco near the northern end of the fault, and then returned with equal fury towards Radicena near Oppido, which was the epicentrum. The statement of Dolomieu on this earthquake is very interesting, especially from a geological point of view. The Apennines, he says, consist for the greater part of granite, and at their base are seen new (Tertiary) strata which constitute the plain of Calabria. The usual effect of the earthquake, he continues, was to disconnect all those masses of newer formations which were supported only by lateral adherence. Hence it follows that throughout the whole length of the chain wide chasms were formed between the solid granitic nucleus and the sandy Flysch soil.

The lines of dislocation of Lower Italy and also that of New Zealand are peripheral, i.e., longitudinal, running parallel with the axes of the mountains; and in both cases it is remarkable to see either that the dislocation has taken place along the boundary of the two entirely foreign formations; or

* *Das Antlitz der Erde.*

else that the direct contact of rocks of different ages has been the result of the faulting or slipping of one upon the other. Geologists are altogether silent as to whether the formation of faults and chasms should be considered as the direct cause, or only the outcome, of subterranean convulsions.

An unique, rhapsodic movement of land, and one which is often cited in text-books on the authority of Sir Ch. Lyell, as evidence of the actual upheaval of a large tract of country, is the formation of Ullah-bund. The 'Mound of God' or Ullah-bund suddenly made its appearance at the time of a violent earthquake which occurred at Cutch, in the delta of the Indus, on June 16, 1819, when the fort of Sindree, on the eastern arm of the river, sank down under the salt water of the Runn. The Ullah-bund is not such a mound as is usually constructed along a river, or thrown across a river-bed. It gives indeed the deceptive appearance of an artificial dam, but only when we behold it far away ; in reality it is the upraised edge of the land which imperceptibly dips away inland. It has also been ascertained that this new-raised country is upwards of *fifty miles* in length from east to west, running parallel to the line of subsidence, while its breadth from north to south is conjectured to be *sixteen miles*, its greatest ascertained height above the original level of the delta being *ten feet.** *Lyell saw in this newly created dam a true upheaving of ground, while Suess considers it in another light. According to him, we have here to deal not with the elevation of land, or with the formation of foldings of strata near the surface, but with the mere settling of the country in consequence of a pressing up of the ground-water of a muddy alluvial plain. These eminent geologists seem, however, to be in accord with the view that the change in the relief in this special case was the result, and not the cause of the terrible shocks which devastated the Runn of Cutch, in 1819.* The question at once arises in the mind, " Was the tectonic disturbance the cause or effect of an earthquake ? "

* Lyell, *Principles of Geology*, 12th edition, p. 161.

The causes of earthquakes.—A popular subject with the men of science of all ages has been the causes of earthquakes, upon which much has been written, but of which little is yet known. As earthquakes are, in one place or another, of daily occurrence, especially in the *ruptured circle* which separates the northern from the southern hemisphere, and as the depths of curiosity are stirred up in the minds of people who have unhappily experienced the startling tremblings of what is usually looked upon as the symbol of fixity—all sorts of explanation have been offered as to their origin; and hence the world has had, both in past and recent times, the misfortune to see the sporadic appearance of monstrous theories on the subject. It lies, however, beyond my present limits to give here the various views as to the causes of earthquakes. This has been already done by Franz Toula in his "*Ueber den gegenwärtigen Stand der Erdbebenfrage*," and readers are referred for details to that small treatise.

One of them is, however, worthy of mention, as it was for a time held in much favour in Europe. Rudolf Falb, the editor of the popular astronomical journal, "*Sirius*," is the chief supporter of this sideric hypothesis.* A cosmic body, especially the moon, is, according to him, able to exert its influence *upon the nucleus* of the terrestrial globe in causing a tide in the interior and simultaneous contraction of the earth, and by so acting may induce a subterranean volcanic explosion which results in a shake on the surface.

While the Austrian journalist is engaged with his favourite idea, but more in popularizing it than in establishing it on a firm scientific basis, we see in another direction an endeavour made to inquire into the causes of seismic phenomena through researches on the formation of mountains. The study in this direction is an effort to bring together into scientific shape the facts ascertained through detail-

* *Grundzüge zu einer Theorie der Erdbeben und Vulkanausbrüche*, 1869.

ed studies of individual earthquakes, and a comparison of the results obtained therefrom with the facts of the geological structure of the region concerned. The chief merit in this line of study is due largely, at least, to the Austrian geologists, Suess, Hoernes, and Bittner. The last-mentioned author gave a finishing blow to the fantastic hypothesis of Falb, in his work on the earthquake of Belluno, in 1873.*

Although we are as yet not in a position to be perfectly clear on the dynamics of the formation of mountain-ranges, still we are already in possession of a certain knowledge on this subject through the study of the Alps. Long ago, Elie de Beaumont saw in the origin of mountains a radial, elevating power, but to this C. Prévost made strong objections. The latter taught us that the elevation is only the effect of a depression of neighbouring regions; and the same view is advanced in the works of Le Conte and of Dana, in a more or less modified shape.

Suess was led by his investigation of the tectonics of the Alps, to express himself to the effect that unequal contraction and the horizontal shifting of the earth's crust resulting therefrom are the cause of foldings of strata.

Again, in his "*Entstehung der Alpen*," Suess says that all mountain-ranges are of one-sided, unsymmetrical structure, the probable explanation being that they originate at the margin of a great depression which exerts a horizontal, lateral pressure. The concave side of mountain-chains on which they face depressed regions we may naturally expect to be much disturbed and ruptured; and seismic activity and volcanic eruptions are usually manifested particularly at this weak point. Professor H. Credner† holds the same view about the

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* *Beiträge zur Kenntniss des Erdbebens von Belluno.* Sitzber. d. k. Akademie d. Wissenschaften. 69 Bd., 1874.

† (a) *Das vogtlandische Erdbeben vom 23 Nov., 1875.* Zeitschr. für die ges. Naturwissenschaften. 48 Bd. 1876. (b) *Das dippoldiswalder Erdbeben von 5 Oct., 1877.* Zeitschr. für die ges. Naturwissenschaften. 50 Bd.

earthquakes of the Vogtland and the Erzgebirge, with regard to mountain-structures. Hoernes tells us in the concluding remarks of his paper,* that earthquakes may take origin from different causes; at one time, the falling in of subterranean cavities, though very rarely, and at another, a volcanic explosion, may bring about locally terrible convulsions; *but by far the greater number of earthquakes and the most terrible ones are the direct outcome of the process of mountain-making.* Under the last category are included those shakings whose frequency and seismic area are more or less closely connected with certain lines, upon which the shakings are repeatedly observed. As they appear to have some direct relation to the activity of mountain-building, Hoernes gave them the name of *tectonic earthquakes.*

Having given a general retrospect of views as to the causes of earthquakes, I may now proceed to the immediate subject of this paper, which is divided into five sections, as follows :—

I. Dislocations.
II. Geology and topography of Mino and Owari.
III. The great earthquake of the Mino-Owari plain.
IV. Various views as to the origin and cause of the earthquake.
V. Relation of the great fault to the recent earthquake.
VI. The course of the line of the great fault that caused the earthquake.
VII. Concluding remarks.

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* *Erdbeben-Studien.* Jahrbuch d. k. k. geol. Reichsanstalt, 28 Bd., p. 448.

I. Dislocations.

Whatever may be the cause, whether depression or unequal contraction of the earth's crust, the formation and structure of mountain-ranges are surely due to the folding, rending, and fissuring of strata. Therefore it is not entirely out of place to insert here some considerations on the topic of *dislocations*, which Professor Suess has ably sketched out in his "*Das Antlitz der Erde.*"

"*Die sichtbaren Dislocationen in dem Felsgerüste der Erde sind das Ergebniss von Bewegungen, welche aus der Verringerung* des Volums unseres Planeten hervorgehen.*" A stress originated in this process may be resolved into tangential and radial components. The first is horizontal, folding and shifting the mass; the second is vertical, often causing a large tract of land to be depressed. The tangential component is more superficial, pressing up the strata into mountains; the radial component acts more profoundly in the interior of the crust, and as a rule volcanic explosions accompany the dislocations due to it.

a) We begin with the tangential movements of the lithosphere. The simplest result of a horizontal thrust of any superficial part of the

* Every theory which has hitherto been proposed to account for the elevation of mountains and the folding of the stratified rocks forming the earth's crust hinges finally on *changes* of temperature. Thus the tangential force generated in the rigid crust of low temperature by the cooling and shrinking of the earth's nucleus has been invoked to account for the crumpling of the crust into mountain-ranges; the crumpling skin of a dried apple being the stock illustration. In this case, the force called in is continuous contraction by loss of heat. The theory which Mellard Read has elaborated is the one dependent upon *alteration* of temperature in the crust, contraction and expansion both being agents of uplift and lateral pressure. Mellard Read: *Origin of Mountain-ranges by Sedimentary Loading and Cumulative Recurrent Expansion.*

crust is the production of a series of folds with alternating geosynclinals and geanticlinals; the crests of such wave-like folds correspond to longitudinal mountain-ranges, the intervening troughs being longitudinal valleys. The direction in which the force acts is at right-angles to the strike of the saddles, or to the axis of a mountain-chain. Folding such as we have mentioned of course involves tilting, and all the different forms of inclination have been described as occurring in nature. We may cite, as an example of such, a chain of the Sambagawan schistose rocks that stretches from the city of Tokushima to Cape Sadano-misaki in the Island of Shikoku; while the valley of the Yoshinogawa, which runs parallel with that range and discharges its waters into Linschoten Strait, may be taken as the model of a longitudinal valley.

When the stowing of mountains and the puckering of beds are carried to a certain degree, the limit of elasticity of rocks will be overstepped, and one effect of this may be that the beds of the upcast side are bodily shoved over those of the downcast side. A set of such "creeps" (*Wechsel*) will produce what is termed the overlap fault or *Schuppenstructur*. At the same time part of a mountain may be dislodged along a fissure running parallel to the axis and strike of a ridge. The movement of a complex of strata in such a case along the line of *longitudinal or peripheral* fault will cause a *longitudinal earthquake*.

If the horizontal force do not act with equal intensity over the area affected by it, one part will be more strongly compressed by it than another, and will consequently be pushed forward along a fissure that is directed at right-angles to the axis of a mountain. In this way, parts of a mountain-chain may be thrust forward along sets of *transverse fissures*. At the same time the strata will suffer downward displacement, and such a dislocation be accompanied by what is called a *transverse earthquake*. That the great earthquake of October last,

should be counted among this class of convulsions will be argued out in detail in the sequel.

β) As we have already said, the stress proceeding from contraction of the earth resolves itself into two elements, of which one acts more or less in a tangential or horizontal direction, while the other works vertically, and dislodges a large tract of land into a *caldron-like* depression. Of the dislocations due to the tangential component, we have already given a general sketch. Now it will be clearly apparent that, while these horizontal shiftings are going on, especially along transverse faults, some parts will receive a passive movement in the vertical direction, resulting in a local downfall of beds and in landslips on a large scale, as if also the radial component were working from great depths.

The genuine radial movement should not be confounded with such a local depression of strata into a hollow in the superficial part of the crust, as that of Fujitani in the Neo valley, which, up to the present, is supposed to have been the sole cause of the earthquake that convulsed nearly the whole of Southern Japan in October, 1891. True radial displacement, of which we are now speaking, is the downward movement of an immense tract of the solid crust, and its effect does not usually come clearly into relief in a country, except in a less disturbed bed like that of the Plateau of Colorado.

The caldron-like depression resulting from vertical displacement, topographically known as a basin, can be found in various localities along the inner or Japan-Sea coast of the Main Island, which curves down from the Kuriles (Chishima) to Kyu-shū, with its convex side towards the Pacific Ocean. Here, as on the Tyrrhenian coast along the inner side of the Apennine curve, we find, with Dr. E. Naumann*, a number of depressed basins, each having a gigantic

* *Ueber den Bau und die Entstehung der japanischen Inseln*, p. 74.

volcano in its centre, such as Iwaki, Moriyoshi, Chōkai, Gassan, Daisen, Sambé, and Aono.

Nearly at the middle of the Pacific side, a notable indentation of the coast-line forms the Bay of Isé, whose northern prolongation is a kettle-like depression. This is the low plain of the twin-provinces of Mino and Owari, which was the scene of the disaster occasioned by the subterranean convulsion in the autumn of 1891. This flat has the appearance of a basin, circumscribed on all sides by walls of mountains, except at its rim on the south, which is, as just stated, open to the Bay of Isé. The west, north, and north-east are built up of Palæozoic formations, while the mass of granites of Mikawa lies on the east.

Mr. Kochibe, of the Geological Survey, *made known in his official report his view as to the cause of the late earthquake, which is based on the assumption that the above-mentioned plain is a geological say or 'Graben-Depression,'* as Prof. Suess would say. He supposes that beneath the surface a number of fault-lines run north and south, and also east and west, and that in consequence of the downward movement of strata interposed between the planes of fault, displacements have eventually formed the present plain ; and he also believes a paroxysmal sliding of a complex of rocks on these old geological lines to be the actual cause of the earthquake. Our geological knowledge of this part of the country is as yet very imperfect, and some time must elapse before we can expect to see any successful attempt to establish so daring an hypothesis on a tolerably safe scientific basis. So much in technical treatment of dislocations.

II. Geology and Topography of Mino and Owari.

We have already pointed out the geographical situation of the provinces Mino and Owari on the Tōkaidō, lying nearly half-way between Kōbe and Tōkyō. The picturesque Lake Biwa with an area of 715,5 square kilometres, lying to the eastward of Kyōto, is separated from the neighbouring Mino-Owari plain by the meridional ridge of Suzuka. The range is mainly built up of Palæozoic formations, with a subordinate mass of young biotite-granite rising to a considerable height, and over which the old road of the Tōkaidō winds up through the well-known Pass of Suzuka (373 m.).

The Palæozoic formations are chiefly composed of multifarious alternations of a greyish, medium-granular, arkose sandstone, and imperfectly fissile, blackish clayslate; with these are associated hornstone and *Radiolarian* slates (Profile *a—b*, Pl. XXVIII.). All these thick complexes are sterile in well-preserved fossils, and as yet no detailed geological studies have been made of them; so that we are at present obliged to call them simply by the vague term of transition formations. There are, however, a few bands of compact limestones inserted between them, which afford tolerably abundant organic remains. These fossiliferous limestones have already been made the subject of a special study * by the late C. Schwager who discovered in them many well-characterized petrifactions, *viz.*:—

Fusulina japonica Gümbel.
„ *exilis* Schwager.
Schwagerina Verbeeki Geinitz?
„ *cruticulifera* Schwager.
Fusulinella sp.

* Richthofen, *China*, IV. Bd.

Lingulina sp.

Tetratatis conica Ehrenberg.

Endothyra crassa Brady.

Climacammina protenta Schwager.

Dr. Gottsche* added to the above list the following forms: *Archaeocidaris*, *Poteriocrinus*, *Pentacrinus*, *Farosites*, ? *Cyathophyllum*, *Pleurotomaria*, ? *Murchisonia*, *Bellerophon aff. hiulcus* Sow., 3 Fusulina, 2 *Schwagerina*, *Endothyra*, *Trochammina* and *Textilaria*.

From what has been given of the organic remains, it is clear that the limestones are of the Carboniferous age, and the thick complexes occurring together with the calcareous beds must represent partly or wholly Palæozoic formations. These Primary strata dip towards the north-west, and their strike is north-south. The ridge of Yōrō (840 m.), which is a detached mass of the Suzuka, rises precipitously from the plain below and forms the western boundary of the lowland of Mino and Owari.

As may be judged from the direction of the limestone outcrops, in the rectangular geological map, Section Nagoya,† the whole Primary formation seems gradually to change the strike at the north-west corner of the plain, and the well-known fossil locality of Akasaka is just at this turning point (Pl. XXX.). Afterwards the strike shifts a little to the north-east, then east to west, and finally, at the north-east corner of Mino, the Palæozoic beds proceed directly in a north-easterly direction far into the mountainous province of Hida. On the east we find the massive mountains of Mikawa, largely composed of granites in which at times hornblende, at others biotite or muscovite, occurs as prevailing component. The granite, frequently

* Zeitschrift der deutschen geolog. Gesellschaft, 1884.

† Published by the Geological Survey of Japan.

showing gneissose structure, takes up large geological blocks or "*Schollen*" of gneiss, gneiss-mica schist, mica-schist and also amphibole-schist, which may be classified into Laurentian, and Upper Archæan (the Takanuki and the Gozaisho series). The writer has been recently engaged in a special study of these ancient rocks, and the results will be found in earlier pages of this volume.

Thus the twin provinces are on three sides bounded by masses of mountains, and in their very centre lies an extensive populous plain, with an area of not less than 1,051 square kilometres or 68 square ri. The general aspect of the plain, which inclines slightly towards the foot of the Yōrō ridge is monotonous and flat. It is covered with a net-work of rivers and artificial canals which, owing to the special orographic condition of the low-lying tract, mostly concentre at the western margin (see Map, Pl. XXIX.). The largest of the rivers is the Kiso-gawa, which starting from the dense impenetrable forest of the Kiso-kaidō, is fed by several tributaries before entering the plain, where it joins with the Nagara and Ibi. These confluent streams branch off at one point and reunite at another, discharging their waters at the head of the Bay of Isé, near the port of Yokkaichi.

The head-waters of the Kiso drain the granitic area of the primeval forest of Shinano, and the swift current, carrying with it an enormous amount of detritus and sand, unloads its contents in its lower course. The formation of the plain is, I think, largely due to the sediments of this river. The lowland of Mino and Owari is usually spoken of as having been once an immense swamp, since converted to the present paddy-land within historical times, and having as the last remnant of its former grandeur the Lake of Shimo-ike, at the foot of Yōrō. It now stands foremost in rank among all the rice-producing districts of Japan, and supports hundreds of thousands of people, Nagoya, Gifu, and Ōgaki being the chief centres of its commerce.

Although the story of the wide marsh seems to be a great exaggeration, still we see in it some germ of truth; for, if all the artificial canals and dams were to be removed, the present fertile land would in a moment be nothing better than a moor. It is these dams and the drainage system that suffered the greatest damage by the last earthquake, so that to reconstruct them in their former state will cost the people an almost incredible sum. The length of embankment and moat, surveyed officially for repair, is not less than 510,5 kilometres.

There are strong reasons for believing that the low-lying tracts experienced the shocks to the greatest degree, not that they were at the epicentrum of the earthquake, but because of the sandy nature of the ground. The soil which makes up the greater part of the paddy-land, especially the eastern, severely damaged by the last earthquake, consists of loose, incoherent, fine sand with but little clayey matter. This soil I consider to have been formed out of the sediment of the Kiso-gawa.

The rivers, Nagara and Ibi, take their origin high up in the Palæozoic mountains of the northern border, and the rocks upon which they exert their denuding action are sandstones, hornstones, and clayslates. The sediments are therefore more or less clayey and heavy. The land formed from the silt of these rivers occupies the western part of the plain, through which they make their way to the sea; and this is the seat of least damage by the late subterranean convulsion.

The North of Mino, as already briefly stated, is a mountainous district, consisting mainly of Palæozoic formations. A cordillera runs from south-west to east, and then north-east, proceeding directly through the province of Hida to the volcanic group of Hakusan of Kaga, the Japanese Alps (Pls. XXIX., and XXX.). It is the main divide which separates the river-systems of the Pacific and the Japan

Sea. Beyond the mountain-ridge lie the provinces of Echizen and Kaga, where the Mesozoic formation is extensively developed, and later on has been intruded into in places by masses of Tertiary eruptives.

A plain of considerable extent, worthy of mention here, is the basin of the Kudzuryū-gawa, in the centre of which lies the city of Fukui. This region felt severe shocks during the late earthquake, and suffered calamity surpassed in extent only by that felt in Mino and Owari. During winter-months the icy winds from Siberia, crossing the waters of the Japan Sea, blow strongly against the ridge, and copiously precipitate moisture in the form of snow. This part of the country presents a dreary aspect, and is untrodden land within the heart of the Main Island. It is rarely visited by geologists, but Mr. Kochibe, during his reconnaissance survey, once crossed the range in going northward from Gifu, through the Neo valley, which is well known since the last earthquake, to Echizen, over the pass of Haibōshi. The line of section, *c*—*d*, Pl. XXVIII., is constructed from his field-sketch, supplemented by one by myself.

This section is one drawn northward from a point south of Yamaguchi up to the top of Hakusan (Gongen-yama), for a distance of 27 km., and goes obliquely through the whole Palæozoic formations of the North of Mino.

Just at the entrance of the valley near Yamaguchi, a bed of hornstone is exposed with a band of limestone in it which encloses abundant remains of crinoids and foraminifera. This complex is followed to the north and overlaid by slate with the strike nearly east to west; then come hornstone, sandstone, and again slate, and so on, with northerly dips usually at very high angles. The lithological characters are rather constant throughout the whole valley, and the multifarious alternations of the above-mentioned rocks constitute the Palæozoic formations of this district. The strike of the rocks remains

the same till we come to Kiré, whence it changes very slightly to the north-west. The youngest and consequently the northernmost of the series is the hornstone of the upper Neo, where it abuts upon the *granite-porphyry* of Hakusan (Hakusan Mayeyama). Near the point of contact an intrusive rock of the character of *hornblende-porphyry* is pressed up through the stratified complex.

The petrographical characteristics of the porphyries are here given :—

a) **Granite-porphyry.**—This is a rock which presents peculiarities in many respects, and is of wide distribution throughout Japan, especially in the highlands of Hida. It was once called granite, then diorite, but now goes generally by the name of porphyrite in all the Geological Survey maps. It is, however, not a typical mica-hornblende-porphyrite, since it is of granitic structure, and contains moreover a large quantity of monoclinic feldspar. On the other hand, the name diorite does not suit it. It resembles a biotite-hornblende granite most closely both in mineralogical composition and in structure; but the presence of porphyritic crystals precludes its being classified as that. It is a greyish-white, mediums granular rock of dioritic aspect, decomposing into angular fragments, like chips of a hornstone-mass. Phenocrysts are scarcely distinguishable in hand-specimens, a-the component minerals are nearly of the same size. *Feldspar* and *hornblende* enter largely into its composition, and, when examined under the microscope, *quartz* and *biotite* are observed, together with *magnetite*, *epidote*, *zircon*, *titanite*, and *apatite* as accessories, the last one being especially characteristic of this rock.

The feldspars are the dominant ingredients, and fall into plagioclastic and monoclinic varieties. Which of the feldspars is present in larger quantity is not easy to say. Speaking generally, the porphyritic, tolerably idiomorphic crystals are mostly but not exclusively plagioclase, with the well-developed zoning which is the characteristic of rocks of a porphyritic structure. The feldspars are mostly oligoclase, sometimes schillerized, extinguishing light at about 13° with the twinning sutures, and with their centres frequently kaolinized over a definitely marked area with patches of chlorite, the surrounding zones being apparently untouched by weathering. The feldspars are the only components that deserve the name of phenocryst.

The rest of the mass is a granitic aggregate of feldspars mostly orthoclase,

and of hornblende, biotite, and quartz. The hornblende, appearing macroscopically as a porphyritic ingredient, is really an accumulation of amphibole and biotite, and these decidedly belong to the second generation of crystals. The irregular plates of hornblende, deeply indented by grains of quartz, and interlarded throughout by prisms of apatite, are of a deep bluish-green colour and pleochroic. The brown fibrous biotite has usually grown with amphibole into irregular tufts, and with them clumps and crystals of magnetite are commonly found. In one slide examined, both magnesium-bisilicates are greatly decomposed into a green fibrous mass, finally changing into a chloritic substance. In this case a large quantity of dust and numerous crystals of magnetite, together with leucoxene, have settled within the confused aggregates, accompanied by secondary epidote.

The feldspar of the general mass is not striped, and is much more decomposed than the phenocryst. Its form is imperfect, being conditioned by the mutual disposition of the same species and of the magnesium-bisilicates. The quartz is present only in small quantity, and is irregular in its form, having filled up the interstitial spaces left by other ingredients. It is of course fresh, displaying the usual vivid chromatic polarization, while the other components are more or less decomposed, and consequently appear dull. Well-finished crystals of it are nowhere observed. It is interesting to note that the quartz contains abundance of liquid and gas-inclusions, the former often holding dancing bubbles and also *small cubes, probably of sodium-chloride*. Glass-inclosures are so far not observed.

Zircon is found in the combination of P and ∞ P, and titanite is found in irregular grains. Apatite is plentiful; its cross-sections are *hexagons with alternately truncated corners*, the longitudinal sections being lath-shaped exactly like those of a tourmaline. Neither the transverse nor the longitudinal section of the apatite becomes totally dark in any position during complete rotation upon the stage. Its crystals contain, especially in their central portion, a large number of gas and liquid-inclusions with spontaneously moving bubbles.

Another slide, made of a specimen from the same locality, presents characters somewhat deviating from the above, in respect to structure, the general mass being for the greater part made up of an intimate intergrowth of quartz and feldspar in *a la gree* form. The general aspect of our granite-porphyry seems to have a close resemblance to the rock, called by v. Richthofen,* the Corean granite, from Kauli-

* "*China*." Cfr. R. Schwerdt, *Untersuchung über Gesteine der chinesischen Provinzen Schantung und Liautung*. Zeitschr. d. d. geol. Gesell. Bd. 38, p. 214.

mon, the Gate of Corea, situated at the south-east corner of Liau-tung.

(3) **Hornblende-porphyry.**—This is a hornblende-diorite-porphyrite, of an ashy-looking aspect, with tolerably large (5mm.), well-defined crystals of *hornblende* as the porphyritic ingredient, seemingly forming dykes in the Palæozoic complex. The general mass is a greyish, fine-crystalline aggregate, in which no other component except the above-mentioned hornblende is to be seen. The amphibole-phenocrysts are of two varieties; the one is in well-defined prisms of compact texture, with the cleavage face perfect and showing a sub-metallic lustre; the other is rather greenish and fibrous with imperfect crystallographic outlines. The distinctive features of the two become more pronounced, when viewed under the microscope.

The compact hornblende is of a deep-brownish colour with different tones in centre and periphery, and is bordered by greyish and blackish granules of *leucoxene*. Its pleochroism is distinct; its outline is tolerably regular, and twinned in that shape which was formerly considered as anomalous twins whose plane of contact was supposed to be the prism $\infty P \bar{2}$ (120).† The other variety is of a yellowish-green, fine, parallel-fibrous texture, resolving oftentimes into chloritic patches. A large quantity of magnetite is present, being scattered through the whole mass.

The rest of the rock is holocrystalline, being built of lath-shaped *feldspar*, *chloritic hornblende*, and black *iron-ore* with borders of leucoxene. The greyish, more or less decomposed feldspar is simply or doubly twinned. There seems to occur another feldspar which is of rather larger size than the other, and of irregular outlines with no signs of a twinning structure. It is probably orthoclase. Allotriomorphic angular *quartz* fills up the interstices left by other ingredients. It is present only in small quantity, and shows a greyish tinge between crossed nicols with undulatory extinction. The quartz contains abundance of liquid-inclusions with spontaneously moving bubbles. The general colour of the ground-mass is grey, on account of the presence of a large amount of leucoxene and chloritic matter, with an aggregate of more or less decomposed, greyish feldspar.

As may be seen from the sketch in Plate XXX., the strike of the Palæozoic formations changes its direction in a most peculiar manner.

† Becke; Tscheramak's mineralog. und petrogr. Mitth. Bd. IV, p. 365.

At first, it points a little west of north as in the Suzuka ridge, then turns to the north-east at Ibuki. Afterwards the strike is due east-west, then again it imperceptibly deflects towards the north-east, retaining the dip always on the left side (compare the profiles *a*—*b*, *c*—*d*, Pl. XXVIII.). In fact, the course of the direction of strike makes a sigmoidal curve, from which it is easy to conceive that the strata must have sustained stress from various directions.

Under such circumstances the axis of the saddles must have received an excessive twisting stress, and we may reasonably expect that during the movement the beds of rocks must have given way to fracture somewhere within the mountain, like the group of fissures in a pane of twisted glass, as experimented upon by Daubrée.* There are, I think, a number of such weak, geological lines in this region as the effect of torsional movement ; the four valleys, Tokuno-yama, Neo, Mugi, and Itatori may be taken as of this class of dislocation, upon which the atmospheric agencies have exercised their denuding action during the course of ages in producing the present deep ravines. As may be clearly seen from the sketch given in Pl. XXX., the courses of the above-mentioned valleys are tolerably regular, running parallel to each other from north-west to south-east, and thus stretching from the Kisogawa to the province of Echizen.

There seems to occur, besides the above-mentioned parallel lines, a number of fissures at right angles to the *paraclases*. These transverse clefts, or to use Daubrée's word, *diaclases*, may be traced in the zigzag run of the valleys. *The valleys in the North of Mino therefore present such regularities in their course, that they can by no means be attributable to the result of mere erosive agencies and their origin must be ascribed to deep-seated discontinuity in the earth's crust* (P. XXX.).

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* *Synthetische Studien zur Experimental-Geologie*, p. 236.

III. The Great Earthquake of the Mino-Owari Plain.

It was on October 28th, 1891, at 6h., 37′, 11″, when the first shock of the great earthquake was experienced, that being far and away worse than any of the many which succeeded it. It brought down the heavy tiled roofs and stone-laden thatches, and in a moment buried thousands of living people beneath them. At Ōgaki, Gifu, Kasamatsu, Takégahana, and many other places, immediately after the first great shocks, fires broke out amongst the ruins, and many who might otherwise have been extricated were burned to death.

In the alluvial plain, especially in the neighbourhood of Nagoya, the ground was riven with myriads of fissures; small mud volcanoes were thrown up along the Shōnai-gawa, comparable to the sand craters of Achaja, in Greece; and for the length of a mile, near Biwashima, a suburb of Nagoya, numerous fractures made their appearance in the banks of this river (Fig. 2, Pl. XXXI.). Here too a very strange thing happened. There was a large bamboo grove and a few pine trees, just at the west side of the embankment, and this slid bodily some *sixty feet* back, the bamboos and trees remaining upright (Fig. 2, Pl. XXXII.). In this figure will be seen a thatched roof fallen intact, and it was in this manner that most of the farmers' houses, which so thickly covered the Mino-Owari plain, gave way, and the country became dotted over with their roofs, which from a distance presented the appearance of gigantic saddles (Fig. 1, Pl. XXXI.).

Going northwards from Nagoya to Gifu, we find a series of villages, one running into the next: that is to say, there is a nearly continuous street of ten *ri*, or more than twenty miles, in

length. The rows of houses were thrown over by the shocks, and these twenty miles of road became simply a narrow lane between two interminable heaps of *débris* (Fig. 1, Pl. XXXII.).

Gifu, the provincial capital, was for the greater part overthrown, and then burnt by fire. Ōgaki, once the resident town of the Princes Toda, seven miles west of Gifu, was entirely levelled with the ground, and then also consumed by fire. Kasamatsu, just on the north bank of the Kisogawa, suffered the same fate, and all that was left of it was a reddish coloured expanse of tiles and rubbish. The fate of Takegahana was as bad, or worse.

What has been stated can convey but an imperfect idea of the destructive work done by the late great earthquake. Still greater convulsions happened in the mountain district of the North of Mino, traversed for a distance of more than forty miles by the line of fault, the birthplace of shocks, where all things were destroyed that happened to lie in the proximity of the great throws of strata, to which I shall have to return in the sequel.

Professors J. Milne and W. K. Burton, of the Imperial University, have given a lively account of the subterranean convulsions in "*The Great Earthquake in Japan, 1891*," illustrated with twenty-nine permanent-photographic plates in *boudoir* size, well printed by Ogawa, and the preceding statements relative to the devastations are mainly taken from this excellent work.

The most dreadful earthquakes within memory were the catastrophes of 1854-55, well known among us as the *Earthquakes of Ansei* (*i. e.*, of the 'Ansei' period), at which time Japan seems to have been the centre of universal earthquakes. Both years proved very calamitous. Nice, Alexandria, and Turin felt more or less severe shocks in 1854. During the following year, 1855, New Zealand, on both shores of Cook's Straits, was visited by a terrible earth-

quake. A shock was felt much about the same time at Truro, South Australia. A fearful earthquake also shook the opposite coasts of the Sea of Marmora; on the 28th of February, and in July of the same year, a smart shock traversed parts of Switzerland, Lombardy, and the south of France.

In the first year of Ansei (1854), the whole of Southern Japan, especially the Island of Shikoku, was visited by terrible subterranean convulsions. The earthquake-period was a long one. In the next year, the centre of the subterranean activity shifted more to the east, and in the greater part of the Main Island, particularly over the districts around the "excellent and singular" volcano of Fuji, towns and villages were reduced to heaps of ruins by most destructive earthquakes. Great as were the effects of the earth-convulsions at that time, the later catastrophe of October, 1891, seems to have been far the more dreadful in intensity as regards Mino and Owari, judging from the destructive effects of the disturbance, and the statements of people who survived the event of the Ansei period.

The Mino-Owari plain (68 square *ri*) is one of Japan's great gardens, covered with rice fields and dotted with clumps of trees and with hamlets; rising from it on the north and south may be seen the castles of Nagoya and Ōgaki. This flat supports a population of perhaps 4,686 per square *ri*, or 304 to every square kilometre, and is therefore the most densely peopled region in this country, except Sanuki in the Island of Shikoku. The meisoseismic area includes all this plain and the mountainous district of Mino and Echizen. By the disturbance which occurred in this portion of the Empire in October, 1891, the land became at once a sea of waves, with movements greatly magnified on the soft alluvial plain. As this lay near the origin of the disturbance, the

waves were short and rapid, and overthrew towns and villages, fissured the ground, and ruined the strongest engineering structures.* According to the official returns, about seven thousand people lost their lives, seventeen thousand were wounded, and two hundred seventy thousand buildings were levelled with the plain, while six thousand houses, less shattered by the shocks, were burnt down by fire.

The following are the statistical accounts of damage in the six provinces, coming under the five Prefectures of Gifu, Aichi, Fukui, Miye, and Shiga :—

Provinces.	Wounded.	Killed.	Buildings entirely destroyed.	Ditto half destroyed.	Burnt.	Shattered and burnt.
Mino	12,311	4,889	114,616	30,994	249	5,934
Owari	4,877	2,357	80,428	43,845	196	—
Mikawa	49	13	1,020	1,464	—	—
Echizen	98	12	1,080	1,188	—	—
Ōmi	47	6	153	366	—	—
Miye	11	2	233	439	—	—
Total	17,393	7,279	197,530	78,296	445	5,934

The following three cases are selected as examples out of a long table, to show to what degree some of the cities and towns suffered in regard to both life and property :—

Names.	Population.	Number of ménages.	Wounded.	Killed.	Houses entirely destroyed.	Ditto half destroyed	Burnt.
Gifu	28,731	6,035	1,200	230	740	3,002	113
Kasamatsu	4,732	1,006	408	221	983	23	553
Takegahana	4,950	1,180	283	268	1,172	2	524

* The account given in this paragraph is based upon that contained in Milne and Burton's *Great Earthquake in Japan, 1891*, already referred to.

But this was by no means all the havoc wrought by the great earthquake. There was not a building in the entire meisoseismic area, and not one of the embankments which have been constructed along the nets of rivers and canals, that wholly escaped damage; and, as I have already said, it was officially reported that the embankments calling urgently for repairs extended for 130 *ri*, or 510 kilometres, while the length of the railroad demolished was found to be 17 kilometres. When steps had been taken to estimate the loss, the amount of injury disclosed was found to be much greater than had at first been recognized. The direct and indirect damage done to the trade and commerce of Nagoya alone, was calculated to amount to 1.778.693 *yen*.

According to the *Official Gazette*, the epicentral district, the seismic area of the first order, which of course included Mino and Owari, along with some portions of the neighbouring provinces, extended over 11, 111 square kilometres, and over this area destruction of buildings and engineering works was well-nigh complete. That of the second order reached as far as Kōbe on the west and Shizuoka on the east, over an extent of 44,907 square kilometres. Within this area several houses fell, walls, embankments, roads, and bridges were partially damaged, and the water of wells rendered turbid. That of the third order, within which walls of houses were fissured, clocks were stopped, and crockery ware, vases, etc., fell off shelves, embraced 52,315 square kilometres. Effects such as the above were produced in the eastern half of Shikoku, and also in Chūgoku, and very much the same thing happened in Tōkyō and Yokohama. Lastly, disturbances were distinctly felt from Sendai, in the north, to the west coasts of Kyūshū in the south, or over an area of 134,722 square kilometres. This was the last or fourth order of seismic area. Altogether, the area shaken by this earthquake in Central Japan will have been about 243,000 square kilometres, or more than 60% of the whole extent of the Empire, as may be easily seen by a cursory glance at the annexed chart.

The earthquake, which brought with it such disaster, seems to have been of a paroxysmal nature, and one for which the inhabitants were totally unprepared. Generally speaking, the frequency of shocks was high during the month of October, 1891, and the earth was by no means tranquil then at any time, especially in the provinces of Musashi and Shimōsa. Seventeen separate quakes had been already recorded by the seismographs, previous to the 28th, all however confined to the vicinity of Tōkyō. Central Japan itself

showed no signs whatever of the coming disaster and there the ground remained quiet up to the very moment when the sudden catastrophe overtook Mino and Owari.

The following table shows the lingering of the after-shocks of the great earthquake throughout the succeeding month, and for several months after, minor shakes, which in Tōkyō would be considered strong, continued to be felt.

Days, 1891.	Frequency of earthquakes in Gifu.	Frequency of earthquakes in Nagoya.	Excess in number of earthquakes in Gifu.	Days, 1891.	Frequency of earthquakes in Gifu.	Frequency of earthquakes in Nagoya.	Excess in number of earthquakes in Gifu.
Oct. 28	102	126	−24	Nov. 14	29	12	17
„ 29	318	135	133	„ 15	29	12	17
„ 30	173	93	80	„ 16	28	13	15
„ 31	126	79	47	„ 17	21	15	6
Nov. 1	99	56	43	„ 18	18	9	9
„ 2	92	30	62	„ 19	17	4	13
„ 3	81	31	50	„ 20	33	9	24
„ 4	78	20	58	„ 21	21	9	12
„ 5	53	20	33	„ 22	12	5	7
„ 6	67	16	51	„ 23	23	9	14
„ 7	45	29	16	„ 24	18	9	9
„ 8	42	18	24	„ 25	9	9	0
„ 9	44	16	28	„ 26	15	5	10
„ 10	40	12	28	„ 27	11	8	3
„ 11	38	5	33	Sum-total	1.757	884	+873
„ 12	40	7	33	Down to the end of March, 1892.	2.588	1.093	+1.495
„ 13	35	13	22				

It should be remarked that the difference in number between the earthquakes which occurred in Nagoya and Gifu is very great indeed, those in the latter amounting to nearly double those in the former, and that from this it follows that Gifu lay nearer to the origin of the convulsion than Nagoya. In the record of the 28th of October, the day of the great event, an anomaly is apparent as

to the frequency in the two cities; but it is known from an authentic source that while the seismic observations were re-opened from 1h., 55′ p.m. in Gifu, in Nagoya they were started just at 1 p.m., the seismographs previously set up having been completely shattered by the terrible shocks in the morning.

Down to the 25th October, 1892, the number of earthquakes recorded on seismometers run up to 2,992 in Gifu, and 1,170 in Nagoya, so that the excess of separate earthquakes in Gifu over those in Nagoya is 1,822.

IV. Views of Others as to the Cause of the Earthquake.

After the earthquake several suggestions as to its probable cause appeared in the newspapers. It will suffice to notice two of these.

Since no volcanic outburst had occurred it was felt by many that the earthquake must have had its origin in the downfall of a superincumbent mass of rock into some subterranean hollow. Among those who advanced such a view of the matter is the Chief of the Meteorological Observatory in Gifu, Mr. Iguchi. Commissioned by the Local Government, he visited the Neo valley a few days after the event, in order to make investigations on the spot under which lay probably the seat of origin of the shocks. The facts stated in his report are interesting and curious. The account of them runs as follows:—

At the foot of the mountain of Haku-san (Gongenyama), 1,811 m. high, which stands on the border of the two provinces of Echizen and Mino, lies Fuji-tani in West Neo-mura, a division of the Ōno district of Gifu Prefecture. It is about 20 kilometres or 5 *ri* from the summit of Haku-san, with chains of hills rising on two sides of it. In this place, some fifty years ago, there appeared two or three holes, measuring 6 or 8 feet across. When stones were thrown into these fissures reverberations caused by their falling could be heard, it is said, for several minutes, from which it may be inferred that the fissures extended to a depth of many hundred feet. At thirty-five minutes past six on the morning of the 28th of October, simultaneously with a deafening noise, enormous landslips in the two chains of hills bounding the district took place. Clouds of dust were thrown up like smoke, to a great height, darkening the whole region, and in many places the contour of the hills was perceptibly changed. At the base of the hills the consequences were not less marked. Houses and fields in the vicinity of Nagamine, Tenjindō, Midori, and Itasho were disturbed, bridges fell, roads were obliterated, and the general features of the landscape were radically changed. The

bed of the river Neo was so much altered that rapids appeared in parts of it which had previously been pools, and deep pools were formed where shallows had formerly existed. *It would seem as though the cause of the last earthquake was the crumbling away of Fuji-tani at the foot of Hakusan.*

By this local depression six seismic lines were formed radiating from this very spot. The first line goes down the valley southwards, bifurcating close to Itaya; one branch proceeds south-eastwards through Takatomi, Akutami, and Inuyama, the other follows the valley down through Toyama, Gifu, and Kasamatsu. The second line takes the southern course along the western ridge of the Neo valley. The third runs north-east over the Pass of Haibōshi to Ōno gōri, while the fifth and sixth go right through Mount Hakusan to Imadate gōri, both in the province of Echizen. *Thus by a landslip of Fujitani, the great earthquake was occasioned, all districts traversed by the above-mentioned six lines being severely shaken.*

Dr. J. C. Berry,* of Dō-shisha Hospital, Kyōto, offered another hypothesis in explanation of the cause of the earthquake, this being the possible dependent relations of seismic disturbances upon the electric condition of the earth.

Dr. Berry, while staying in Ōgaki, experienced the severe shakings and the distant thunders of the shocks, sometimes heard for three seconds (?) before the tremors could be felt. *He was profoundly impressed with the thought that nothing but the power of electricity could produce this result. He regards an earthquake shock as but an electric storm in the earth.*

* *The Japan Weekly Mail*, Nov. 14, 1891, Yokohama.

V. Relation of the Great Fault to the Recent Earthquake.

As introductory to the account of the late event, it seems well to insert here a few notes of my own experience of the earthquake of Kumamoto, of which no details have as yet been given in any foreign language. *On July 28th, 1889, a violent earthquake occurred in the neighbourhood of Kumamoto, a flourishing city in the Island of Kyū-Shu.* Being entrusted by the Geological Survey with making a reconnaissance survey of the province of Bungo, I was at the time engaged in that work in the vicinity of Cape Sagano-seki, and thus had the fortune to feel the shocks which caused much damage to both life and property in Kumamoto, killing fifty-three persons and destroying about four hundred and sixty-three houses. On receiving the intelligence of the catastrophe in the neighbouring province, I immediately started for the scene of disaster to examine its effects, and on my arrival saw a large number of houses that had collapsed, and many others supported from falling by wooden poles.

The night of the 3rd of August was particularly distressing. Shocks came regularly almost every hour, seemingly increasing rapidly in intensity. At last, at about 2h., 18′ midnight, a great earthquake, next only to the shock of the week before, visited Kumamoto, throwing the whole city, with its population of fifty thousand, at once into wild agitation, and filling the mouths of one and all with the question, where was the source of the disturbance.

To the west of the city of Kumamoto lies an extinct volcano, locally known as Nishi-yama, the "western mountain," whose effusive nature was then hardly suspected. Ascending it next day

I found it to be a typical volcano, with the somma, caldera, and barranco all preserved; and at its centre, as is usually the case, standing somewhat excentrically, a sharp conical point, called Kimpō-zan (Kibō-zan). Within the atrio are the villages of Noidé, Ononoki, and Hirayama. Tracing the positions of the landslips and of the destroyed houses of the villagers, *I became convinced of the fact that there are two main lines, along which the hills had glided, houses been shattered, and the ground convulsed and broken into chaos* (see the map PL. XXXIII.). The first line runs from the north-west along the Kawachi valley through Hirayama to the small but thriving town of Takasé. The second taking the same direction starts from Noidé, at the southern foot of Ninodaké, which seems to have been the active centre, proceeds through Daké down to the southern slope of Arao-yama, and thence to the city of Kumamoto. Between the two nearly parallel lines stands the Peak of Kimpō-zan. The second one sends off a branch line to the east down to Tōmonji.

These seismic lines, by which I mean the lines of fault, are not favourably visible on the surface as in the case of the recent catastrophe of Mino and Owari, but still I think I was able to trace them by the fissures in the ground and along the slopes of the hills. The facts that Kimpō-zan, the whole group being generally called by this name, is volcanic, being made up of augite-andesite; that the faults though very indistinct are found there in three lines; and, lastly, that the seismic area was considerable, embracing the whole of Kyū-Shū, as well as a part of Shikoku and the west end of the Main Island,—*all seemed to me to point to the conclusion that the seismic disturbance in Kumamoto was caused by a combined process of dislocation and an unsuccessful approach to a volcanic explosion. Which of these will have been the main factor in*

producing this dreadful calamity, I am quite unable to say. The lesson I have learned from this physical convulsion of Kumamoto, is that a violent earthquake often manifests itself its activity along some narrow line or fissure within the earth's crust.

The residents of Tōkyō experience yearly about sixty earthquakes which are, as a rule, fortunately of a feeble nature. These comparatively speaking languid earthquakes and such paroxysmal varieties, as the convulsions of Kumamoto and of Central Japan, show some great differences between them in their effects, but these are not fundamental. Terrible dislocation-earthquakes present special features of their own, not usually observed in slight shocks. The seismic disturbance in the latter is not so uniformly felt over a large area as in the former. On the contrary, the severely shaken area is commonly confined to a narrow zone, say a valley or a mountain slope. In other words, strong earthquakes possess *seismic lines*, as in the case of Kumamoto.

On account of this peculiarity, a series of towns and villages, one running into the next, may be completely shattered and laid in ruins, while at a short distance on both sides damage is comparatively slight. While travelling in Mino and Owari after the great convulsion, I frequently heard people complaining of their own deep suffering, and grudging the happy state of villagers just a few kilometres away. Dr. Berry* puts the matter well in saying that he witnessed all over the region (Mino and Owari) the peculiar freaks and destructive violence of its (the earthquake's) course—leaving houses untouched, passing under whole villages, and only to appear again miles beyond with destructive violence. Even in common earthquakes such as are experienced weekly in Tōkyō,

* *Loc. cit.*

such seismic lines or zones may possibly exist just as in violent earthquakes; but as their magnitude is very small, these lines must generally escape our recognition, and it is habitually, though erroneously, considered that the disturbance is uniform over a circular seismic area.

When the intelligence of the outbreak in Mino, Owari, and Echizen, which took place on the morning of October 28th, 1891, was received in Tōkyō, seismologists, architects, and other representative scientific men were sent out to the shaken district from several Government Departments. Particulars of the earthquake soon began to reach Tōkyō, but nothing of any volcanic eruption having anywhere taken place.

A telegram from Gifu announced a rumour that the centre of the seismic disturbance must be in the neighbourhood of Neodani. Report of remarkable physical changes in that quarter having been received, an official of the Meteorological Bureau was sent thither, and he reported that at Nogō a marked subsidence had taken place, and that the general appearance of Midori had undergone a complete transformation. On hearing this news, I started for the scene of disaster to examine *lines of fault like those in Kumamoto*, should there be any in the devastated region. I ascended the Neo valley, which is said to contain the source of the great earthquake, and found the condition of things very remarkable. The first thing that attracted attention were many boulders that had been hurled from the steep mountain sides, the number of which increased at about Kimbara to such an extent that practically the sides of the valley had slidden into the river, while the road had totally gone in places. Ascending the valley higher, landslips were more

and more frequently seen. Indeed in the upper dale it may be said that the greater part of the mountain slopes had slipped away, carrying with them the forest they were covered with.

Amongst the extraordinary things done by the earthquake, one that always drew my attention was the earth-rent. It strikes across hills and paddy-fields alike, cutting up the soft earth into enormous clods and raising them above the surface. *It resembles the pathway of a gigantic mole more than anything else* (Pl. XXXV.) Indeed it is known by this appellation among the villagers. An old Japanese superstition about earthquakes is that a monstrous cat-fish lives underneath the Empire of Japan, and whenever this fish moves there is an earthquake. The origin of this belief is not known, but no doubt it has undergone several changes or modifications since it was first originated. A representation of it was given as a drawing in an almanac of the eleventh century. There it was depicted as the *earthquake-insect*—a wonderful flat creature with numerous appendages and a head like a dragon, carrying on its back a map of Japan. *The earth-rent which has very much the appearance of the track of a mole, as just stated, strongly reminded me of the fancy of the earthquake-insect. It is probable that the belief of the earthquake-insect as the author of subterranean convulsions may have arisen from the outward aspect of the fissure, produced by a tectonic earthquake as in the case of the Neo valley.*

The formation of crevices is the never-failing attendant phenomenon in violent earthquakes ; but the one in question is not of a common sort. Being interested in this remarkable earth-rent I have actually traced it for more than forty miles. It starts from about the village of Katabira, not far from Katsuyama, on the bank of the Kiso-gawa on the Nakasendō, running north-westwards up to Fukui in Echizen through the Neo valley (Pl. XXIX.). Although the

geological structure of the region traversed by this great fault is not so well known as that of Lago di Croce in the Eastern Alps, still I think, as has been already pointed out, that I am justified in supposing the existence of a number of shifted lines of dislocation, stretching from north-west to south-east across the North of Mino. *The event of October*, 1891, *seems to me to have been a renewed movement upon one of these prëxisting fissures—the Neo valley line of fault, by which the entire region lying to the right of it not only moved actually downwards but was also shifted horizontally towards the north-west for from one to two metres along the plane of dislocation. This vertical movement and horizontal shifting seem to me to have been the sole cause of the late catastrophe.*

VI. The Course of the Line of the Great Fault that caused the Earthquake.

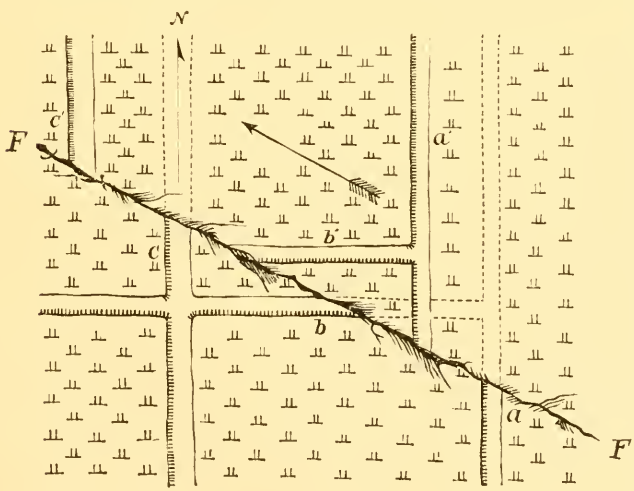
The great earthquake of Central Japan shook the extraordinarily large superficies of 243,055 square kilometres, or more than three-fifths of all Japan, and must be counted as one of the greatest physical events of modern times. Let us see now how the fault looks which produced such a tremendous effect?

Faults or throws may be observed almost everywhere in the earth's crust, and geologists and miners are quite familiar with their structure. But it rarely happens that a fault comes into relief in complicated mountainous districts. In less disturbed regions such as the Plateau of Colorado, or the eastern border of the Central Asiatic plateau, the lines of displacement can be traced with great certainty; and the underground structure is usually reflected in a great measure in the topography of the region concerned. In the Alps and Central Europe, most of the earthquakes have hitherto been ascribed to a tectonic movement of the solid crust through lineal extension of the disturbed area, but no actual fault has anywhere been found which was formed at the time of an earthquake, and could be reasonably assumed to be the originator of the disturbance.

The case of 1891 is quite otherwise. Here we could not only positively observe the fault on the surface, but also measure the height and length of it. At a place called Midori in the Neo valley, the flat bed of the valley was split longitudinally, and one side was tipped off so that there is an abrupt step, measuring 5.5 to 6 metres vertically. The earth very regularly took its angle of repose at the break; and the appearance, as we come to it eastwards from below, is as if we were approaching a railway embankment (Pl. XXXIV.).

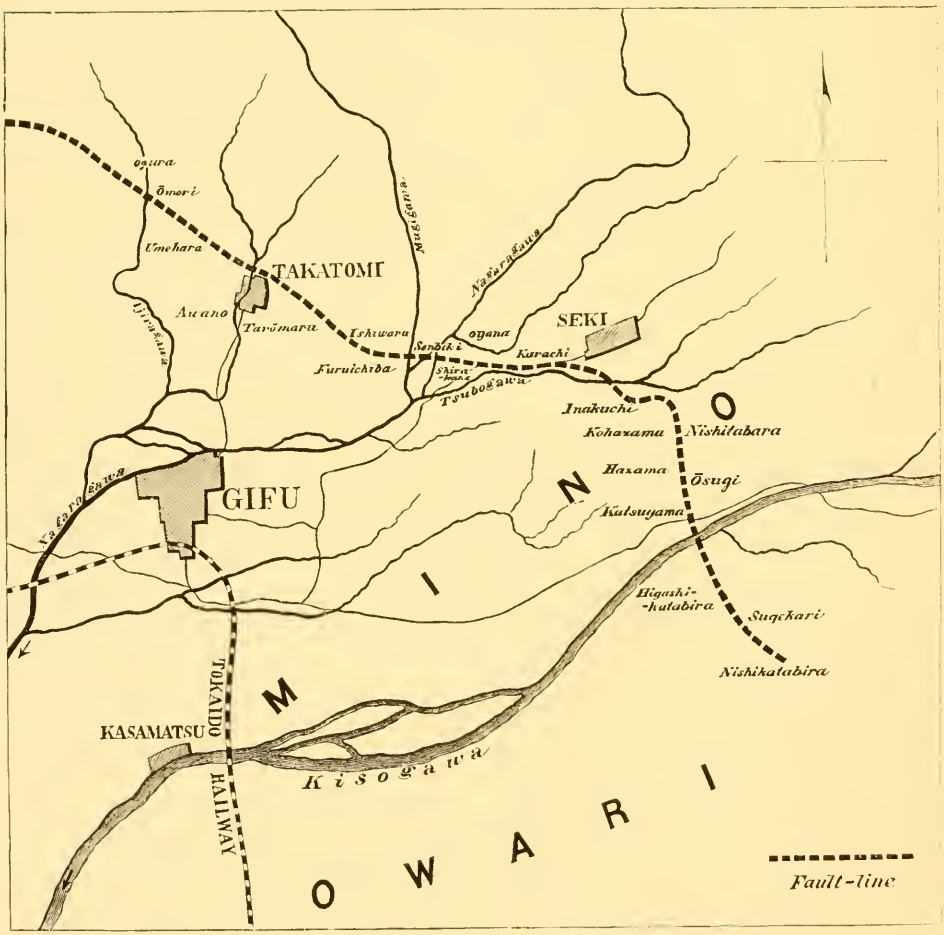
Where the vertical displacement is not considerable, the line of the fault appears on the surface like a rounded ridge of soft earth 30 to 60 cm. high and, as I have already stated, *resembles very much the pathway of a gigantic mole* (Pl. XXXV.).

In tracing the course of the great fault (indicated by the heavy line, Pl. XXIX.), I begin with what I suppose to be the south end.* In Nishi-katabira, a small village amidst hills of a greyish Tertiary sandstone, in the district of Kani, Mino province, there is a place locally called Kozé. Here, upon the slope of a spur of hill, stood the old monastery of Fukudenji. The hill together with the entire building slipped down into the paddy-field which in turn was broken into clods of earth, and swelled up 5 metres high. Following the direction of this remarkable landslip towards the north-west, the paddy-field was seen sharply cut by a line, along which *the north-east side had slightly subsided, and had moreover been shifted horizontally towards the north-west for a distance of 1 to 1.2 metres.* That besides the vertical movement an actual horizontal shifting had taken place is proved by the fact that the originally straight mound or ridge called Azé which separated neighbouring fields, was



* On close examination in the field, especially at about Kukuri, Ikeda, and Takayama, I was not able to find any trace of the fault, which may be looked upon as the prolongation of the main line of dislocation.

now cut obliquely and sharply by the line of fault. Moreover, the continuity of the mound was really broken and the mound with the entire ground so shoved forwards that the detached ends could not afterwards be rejoined—(see the accompanying wood-cut). It is evidently quite different from what the miners call a 'heave',—an *apparent* horizontal displacement of strata by a *mere vertical* throw in inclined beds, for in the present case the horizontal shifting can be actually traced in *perfectly even ground*.



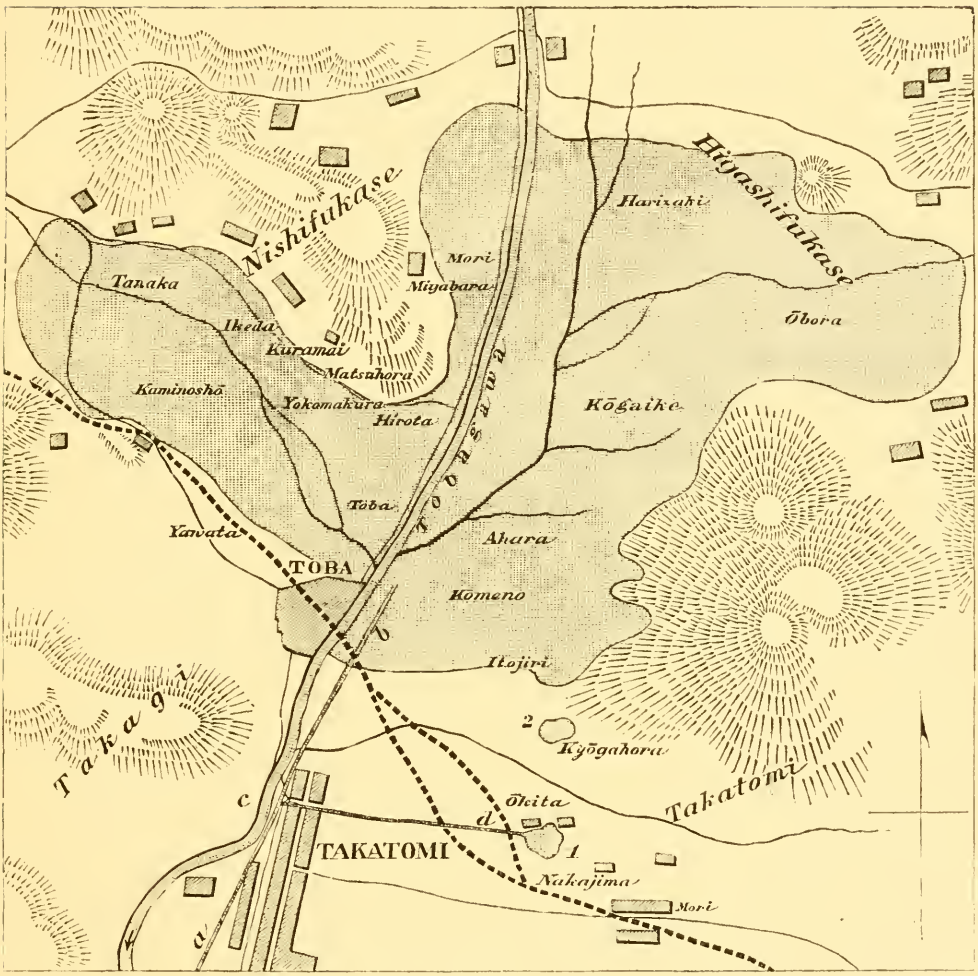
Sketch map between Nishi-katabira and Ogura in Mino province, showing the course of fault (heavily dotted line). After S. Mori.

The above-mentioned line takes the direction of NNW. At Tsuchida, ground was depressed for a mile's length along the embankment of the Kani river, a small affluent of the Kiso-gawa. Mount Daitenjin, lying to the south-west of Tsuchida, on the south side of the Kiso-gawa, was sharply cut by the line of dislocation, and the east side of this hornstone-slate mass slipped a little downwards. The vertically dislodged line is visible on the steep precipice of rugged hills, at the foot of which the Kiso-gawa foams over its rocky bed. The line crosses the bed of the river at the east end of Katsu-yama, on the Nakasendō, and completely reduced the village to a heap of rubbish. We find here terraced ground for raising wheat and barley on the hill slope, and a piece of this ground about 2,000 square metres (2 *chō*), lying within the precincts of the Buddhist monastery of Kakuzenji, was so thoroughly turned over from the very bottom that all the original marks were entirely effaced from the dry field (*hata*), and there remained but clods of earth and upturned roots. Although nothing of the under-ground solid crust was to be seen on the surface, still it is almost certain that the origin of the disturbance did not lie within the superficial covering of the soil, but must be sought for in the deeper portion of the crust. It appears as if the loose soil had been jerked off from the hard under-ground by an intense shock from below.

The main line of disturbance now points N. 10° W.; it then goes through spurs of hills and paddy-fields, causing damage to the villages. Ōsugi, Hazama, and Nishi-tabara. After making a sinuous curve it crosses the Tsubo-gawa, passes through the villages of Kurachi and Oyama, crosses the Nagara-gawa at Shimo-shira-gané, and then taking a north-westerly direction, goes through Sen-biki and Toda, passes over the Mugi-gawa, and proceeds towards Mori and Sebo, till it reaches Ishiwara. In the last-mentioned

village there is an artificially constructed pond of considerable size, for irrigating neighbouring paddy-fields. It was fed by a small stream from the north with its outlet on the south, but the line of fault going right through the middle of it in the east-west direction, its northern half together with the neighbouring fields of 17,851 square metres (1 *chō* 8 *tan*) subsided, and was also shoved a little to the north-west. The result of this vertical as well as horizontal movement of the north side was that the outward passage at the south end of the pond lies now on the higher level. The quantity of water remains nearly the same as before, and the deserted pond is still fed from the entry passage on the north, so that it is probable that the water soaks away through the new fissure as fast as the small current enters the pond through the channel.

The line now runs, through Taromaru, a few steps southwards along the newly macadamized road that connects Seki and Takatomi. One could easily recognize the fault as such by a slight difference in the level of a perfectly even field, the north side being a little the lower. About five hundred steps east of Takatomi, it crosses the road obliquely at Mori, and the north side became again the lower by 1.5 metres and at the same time was horizontally shoved about 1 metre westwards. Takatomi is a tolerably large village, with a population of 1,746, lying north of Gifu, and I saw in no other place within the devastated region such a complete destruction of buildings as occurred here. All was shattered and levelled with the ground. About 87 persons were killed and 158 wounded. At the north end of the village the fault appears in double lines (see the accompanying sketch map), along which the ground had been shifted horizontally, and also become continuously lower towards the north, so that a once even paddy-field now forms a good natural slope.



Scale 1: 25,000

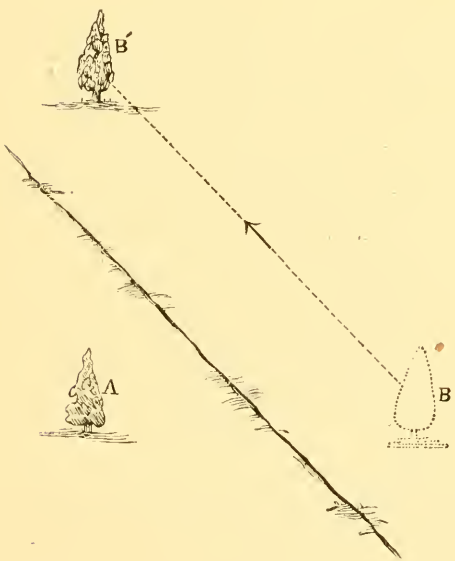
Sketch map of the environs of Takatomi, showing the course of fault (heavily dotted lines). The stippled portion on the right is the depressed side of the fault being the newly created swamp of Fukasé: ab, the new channel specially constructed for drawing off the waters of the swamp. (1) and (2) the two other depressions formed at the time of the earthquake, now filled with water: cd, being the channel for the pool (1).

The small Toba-gawa, rising high in the northern mountains, flows down by Takatomi towards Gifu, to join the Nagara-gawa. By the great earthquake a tract of land and the river bed, lying to the north of Takatomi, were considerably lowered, so that the contents of

the Toba-gawa lost their outlet, and the villages of Nishi- and Higashi-Fukasé, comprising an area of 2 square kilometres, or nearly 220 *chō*, were transformed into a deep swamp in consequence (compare the annexed sketch map). When I was there last autumn, the farmers were obliged to cut the grain in boats, October being the month of the rice harvest. It was very remarkable to see that a group of farmers' cottages, standing at the northern border of the newly created swamp, had miraculously escaped the collapse, though scarcely 2 kilometres north of Takatomi, a phenomenon due perhaps to the fact that the place is just behind a low hill which seems to have absorbed the wave motion of the earthquake on its way. The earthquake-shadow so created, finds analogy in the action of a strongly blowing wind, cut short by a hill in its path, leaving the other side in the wind-shadow. It is almost beyond doubt now that the destructive motion of an earthquake depends like that of the wind, more upon the topography of the shaken district than upon the angle of emergence of waves from an assumed origin within the earth's crust. I could easily multiply such examples of the earthquake-shadow between Takatomi and Ōmori along the great fault. Houses between or near side-valleys generally escaped the destruction, while those on the plain through which the line passes, could not withstand the shock and were thrown down.

The great fault-line crosses Toba, where the houses were crushed to rubbish, and proceeds directly westwards to Horachi. In the latter place again the north side subsided and became part of the new swamp, already referred to. The line enters a hill at Mochi-nari, cuts through a spur of hill at Azuki-zaka, and then follows the northern foot of the hills westwards. It appeared for some time after on the surface through the whole region, exactly like the track of an enormous mole.

It goes right through the hamlet of Jōbara (Uméhara),* where, in a front garden adjoining a farmer's house, there are two stately persimmon trees, *Diospyros kaki*, which had stood time out of mind in an east-west line. The line of fault traverses the space between the two from the south-east to north-west, and as usual the north side was shoved north-west, so that, to the great astonishment of the owner, they now stand in a north-south line instead of east-west, without being in the least impaired, and still adorn a corner of the inclosure. The plane of dislocation, which served at the same time as that of shifting, appeared on the hard face of the ground as a *mere line*, so that to any person not initiated into the structure of a fault the displacement of the trees was quite unintelligible, and appeared to the astonished peasants as a marvel with no apparent cause. A few doors beyond, there was a water course in front of a cottage, as is common in Japanese villages, which being cut by the line of fault, and the ground on which the house stood, sinking slightly, unexpectedly inundated the place. After this, the line appears in the muddy fields of Nakamura and Kōden, with the north side dislodged. In consequence, a second swamp resulted which has an extent of 25 hectares, or nearly 25 *chō*. From here to Ōmori the road ascends the slight elevation of Koshigirizaka, at the very top of which the fault cuts off the solid rock, leaving the north side depressed.



* See the sketch map, p. 332.

The villages of Ōmori, Ogura, Fujikura, Horada, and Matsuo are all clustered in a basin-shaped widening of the Ijira valley, which in conformation with the general system of valleys in the north of Mino, runs in a south-easterly direction across the strike of the Palæozoic formations. As it is situated in an old river bed, Ōmori suffered the most by the earthquake, many portions of the soil being raised or sunk, and innumerable fissures traversing the village in all directions: so that it is somewhat difficult to follow the main fault in such a chaos. The whole system of drainage was deranged. The line of displacement next crosses the bed of the Ijira-gawa, cuts obliquely through the boundary of Horada and Matsuo, passes over the top of a hill, called the Nishimuné pass, at the border of the three districts of Yamagata, Katagata and Motosu, and then descends to Kawa-uchi (Toyama), with always its north side depressed, and as observed by me driven northwards for about 2 metres. The rent then points north-north-west, runs along the eastern slope of the hill in Toyama, appears on the steep descent of Kané-zaka on the way to Kimbara, proceeds thence directly northwards along the western declivity of the hill, and enters the Neo valley for the first time at Kimbara from the Ijira valley lying east of it.

When it had become current that the source of the earthquake had been in the Neo-dani, many people ascended that valley in order to satisfy their curiosity to see the site from which reputedly the severe shocks had originated. They usually took the road from Gifu through Yamaguchi at the entrance of the valley, along the Neo river to its source, and in so doing, were somewhat disappointed while ascending its lower course. Less destruction was visible than was anticipated, an impression produced by seeing some houses still standing, after having passed along the road in the Mino-Owari plain lined with ruined houses on both sides, and many visitors positively

asserted that the earthquake could not have originated in this valley. Had they come to Kimbara, where I left off the description of the earth-rent, this notion would soon have vanished.

Kimbara itself lies on the left of the fissure, but so near to it that all the buildings in the village entirely collapsed. At the north end of it the road descends the steep slope of Dando-zaka, and brings us to the beginning of the place of greatest destruction in the valley. Beyond the steep descent there was no trace of road left by the earthquake; rubbish and blocks of hornstone had obstructed and buried it under them. For a few days after the great shock there was still every now and then, the crash of some mass of rocks falling from precipices on either side of the valley that had been left by a landslip.

The rent now runs east of Hinata, where the river bed makes crooked turns, and at Hirano, the next village, passes on the right, and at the south of Midori, it appears on the left side of the Neo-gawa, and here one of the most wonderful effects of the earthquake was to be seen. A fine new road (see Pl. XXXIV.) leading to Gifu had been obliquely cut into two, and the lower end with the surrounding fields had sunk about 6 metres below the upper end. The road is here on the west side of the river, and the eastern half of the valley, which includes the Neo-gawa and opposite hills, shows the tilting edge, or cutting of the fault. That the *east half had been pushed 4 metres northwards*, in conformity with the general rule, is well seen in the photograph by an abrupt change in the direction of the displaced road. So far as I am aware, the formation of such a colossal fault on the surface, as this in Midori, is exceptionally rare, and finds its equal only in the 'Ullah-bund,' or God's dam at the Runn of Cutch, in the lower course of the Indus.

Those who have followed me with patience to this point in my

description of the earth's rent from the village of Katabira, will have seen that I have always spoken of *subsidence of the right side*, accompanied by *horizontal shifting towards the north or north-west*, and now looking at the fault at Midori, may object to my contention that the great throw is a prolongation of the main fault, that the *west half* had here sunk instead of the *east*. It seems, however, that we have here an abnormal case, and that the *east half, including the river became raised. What would seem to favour this view is that a little higher up the river what was formerly a shallow rapid stream 27 metres across and easily fordable, broadened out into a small lake, 63 metres in width, of still water which a boatsman's pole cannot fathom.* A dam was formed below and the current now finds its way in a narrow diverted stream under the opposite hills. In explanation of this special case, I would say that, in the enormous convulsion caused in the valley between the two chains of hills, the weight of the hills on either side caused a cracking and upheaval on the east side of the valley, in the same way that a severe shaking given to a heavy abutment of an arch may force up its crown or centre.

At the north end of Midori, the road crossed the valley to Itasho, where there was formerly a bridge ; but it is now necessary to cross in a ferry boat, the valley having been transformed into the lake, already referred to. At Itasho, again the fissure appears being like a mole's track when seen by me, both sides being nearly on the same level, though the east half had been shoved northwards as shown by the horizontal displacement of a broken ditch in the rice fields. It passes through Ichiba, and Kōdokoro, reappears on the road at Naka, and goes through the middle of the fields at Osso, with its usual characteristics.

The villages of Kadowaki and Nagaminé lie out of the exact line of rent, and the damage suffered by them were therefore comparative-

ly speaking not very heavy. Still it is not to be supposed that their houses were entirely spared, the whole surrounding soil at the time of the great earthquake heaving in a state of vibration and doing much mischief. There was terrible destruction on the line, as in Tenjin-dō, a few hundred steps beyond Nagaminé. The next village is Nagashima where the rent was to be seen on the road side. The ground was bodily shifted with the houses 2 metres forward, and subsided 1 metre on the right side. Turning off from the main course of the Neo, and passing over by a bridge to Nogō, we find the rent striking across the mountain stream, depressing the eastern portion of the bed, and thus converting a torrent into a slow stream.

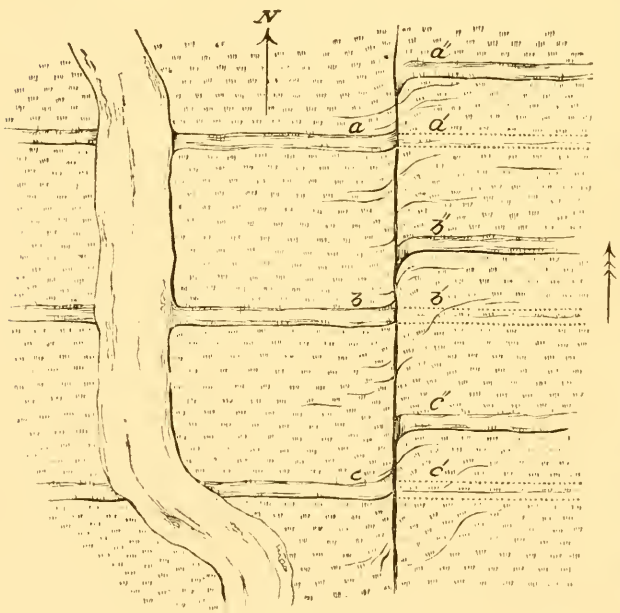
Running northwards, it enters the hill at the back of the temple of Gongen, having caused landslips all along its path. This temple was founded in 717 in honour of the Gongen of Haku-san, a Japanese deity in a Buddhist form, and though small in scale was of ancient date, having been erected in 1673 on the southern slope of the hill, overlooking the Neo-gawa. This wooden building of rare antiquity for Japan was hurled to the ground in ruins, attesting how long a period had elapsed since a shock of similar violence had visited that quarter. Yet if we were asked whether the twin provinces of Mino and Owari were a place where earthquakes had not been frequent we should reply in the negative. In Japan there are some seven hundred stations where earthquakes are observed, and from several of them situated in the Mino-Owari plain, we find that in the six years from 1885 to 1890 the number of shocks recorded in that district have been respectively 9, 4, 10, 12, 15, and 36.* Still going backwards in the annals of earthquakes, we find again that violent disturbances took place in the district in 745, 762, 1596, 1707, 1723, 1819, and 1854. Many dwellings, store-

* Milne-Burton, *The Great Earthquake of Japan*, 1891. p. 6.

houses, and even mountains suffered, people and animals were killed, rivers were stopped up, and floods were occasioned. But in spite of these subterranean convulsions, the temple in Nogō, erected in 1673, had stood well-preserved down to the present generation.

From the facts already given, it seems not improbable that the centres of disturbance of former times have not been located in the Neo valley. In pre-historic times, however, there must have occurred several great earthquakes, as is evinced by the geological structure of its mountains. In the great earthquake of 1854, which is still within the memory of many, the Neo valley had been but very little disturbed, we were told by old folks in Nagaminé, whose houses had collapsed completely in the last catastrophe, and that many of them built more than a century ago, had remained till that event in tolerably good condition, and without being impaired by any former earthquake.

The rent appears again at the bottom of the Konokana-dani, a side-valley which we followed up from Nogō, here diverting the main course of the Neo-gawa. It might be traced with great exactitude as far north as the entrance of the sunken gully of Fuji-tani, where the line of displacement of the rocks appeared on the surface like a rounded ridge of soft earth 1 to 1½ metres high, as seen in Plate XXXV. The ground had been



depressed on the right side, and shifted horizontally in the usual manner, as will be clearly understood from the annexed wood-cut. Lastly, we arrived at the place called Fujitani, which is now tolerably well known through the suggestion of Mr. Iguchi, that it was the seat of the source of the earthquake. It is a branch valley of the Konokana-dani, circumscribed by hills, except on the south. At the centre of it, we were told, a hole 1 to 2 metres in diameter had existed, into which large stones and boulders being thrown were heard for some time striking and echoing in their descent to an (?) unfathomable depth. Time had closed, it was said, the opening, and there remained but a shallow depression in its place. The ground indeed had been intensely convulsed, and the face of nature entirely changed. The sides of the hills which flanked the valley had slipped down, and the forest upon them still presented a singular scene of confusion; trees standing inclined in every direction, many with their trunks and branches broken. The course of a small stream was stopped and a new lake were created there. When these marvellously great changes occurred, the shaking must have been terrific—inconceivable—yet I cannot believe that the slight depression in Fujitani to have been the origin of an earthquake which had shaken a great part of Japan. The sunken gully of Fujitani, already alluded to, is only a prolongation of the rent which we followed up there for about 52 kilometres.

The fissure cuts off the rear of the depression of Fujitani, and comes in sight again beyond the hill of greywacke sandstone and clayslate, at the bottom of the main course of the Konokana valley, which terminates at the foot of Front Haku-san. The valley here is narrow and forms a deep gulch, bounded by overhanging precipices on the east and west. By the earthquake, the surfaces of hills on either side slipped down the valley, and left them almost bare of the fine timber which had clothed them. The fresh verdure of the steep

mountain-side had given place to a rocky desert, and even, as we passed down, avalanches of rocks, accompanied by a noise like that of an immense torrent or cascade and by a vibration of the ground, occasionally occurred. The shocks had been far more destructive there than in Fujitani. If any one had been as the villagers were, in a position to look on at a distance at this colossal sliding of hills, he would have seen columns of dust rising up, and heard tremendous sounds, and might have taken these phenomena as those of a volcanic eruption, for the effects of landslips and volcanic explosions closely resemble each other. The configuration of the valley was entirely changed; the course of a small stream, running on its west side, was transferred to its east side, and at places now takes an underground course, reappearing farther on. Unfamiliar obstacles made themselves apparent, and small hills covered with forest had come into sight which had not been seen before.

At about 10 kilometres from Nogō, the earth-rent goes over to the left and cuts the top of a ridge, called Shijūgara-daké, right through its middle. We passed a stormy cold night in the open air on this summit. The line of fault then enters Shiratani, a branch of the Tokuno-yama valley which, as I have already said, runs parallel to, and lies to the west of the Neo valley. The gulch of Shiratani was severely torn and rent. It appears shattered and half-naked, and no longer affords a fine green prospect, as before, but is stripped of its woods and natural verdure. The fissure advances still further northward, touching the eastern shoulder of Haku-san.

So far we had traced the great earth-rent up to the north boundary of Mino, beyond which is the province of Echizen. It was the 16th of November, the nineteenth day after the earthquake, when I began the ascent of Haku-san, in company with Mr. Wakimidzu, a student of geology. But it was too late in the season to go on. The

weather was cold, and some of the high points were already white with snow; mountain-passes had become impassable, the road had totally gone in places, or left nothing but a difficult foot path. Such being the state of things, I had to abandon the idea of reaching the town of Fukui by the pass of Haibōshi, and returned direct to Gifu, for many additional days would have been necessary to get to Nukumi, Kumagō, and Minomata, all in Echizen, where extensive landslips were said to have taken place.

Although I could not examine personally the devastated region in the south-east of Echizen, at the boundary of Mino, still I am fortunate enough to have received several reports from village-masters and the police authorities of Nukumi, and, last but not least, from Mr. Hiki, another student of geology in the University. From their brief accounts it seems highly probable that the rent proceeds from the summit of Haku-san to the poor hamlet of Nukumi in the district of Ōno, where eleven out of thirteen houses were completely shattered and the remaining two narrowly escaped collapse. It is stated in one of the reports that there is a fissure running from south-east to north-west, just as is the case in Mino, and that one side of the fissure has been bodily shifted horizontally for about 3 metres. It passes by Kumagō,* along a rivulet, and then crosses the pass of Minomata down to the village of the same name on the western foot of the ridge. The line seems to continue through the villages of Anzenji, and Mizumi to Taniguchi, and eventually reaches Hirose, after traversing the bed of the Asuwa-gawa which flows at its lower course by the city of Fukui. Throughout the valley of Minomata, dotted with the above mentioned hamlets, extensive landslips are said to have occurred, causing damage to both life and property. To the westwards within the Tertiary terrain, I

* It is erroneously spelled as *Kumagaica* in the map, Pl. XXIX.

am not quite sure of the presence of any fissure as the prolongation of the great fault-line, still I have strong reason to believe that there were faint indications of such a rent in the lineal extension of the disturbed area, which beginning at Hirosé, extends over Nishi-kōchi, Ainoki (between these two villages is the slight elevation of Nakaban-saka, much disturbed by fissures), Ochiai, Kawashima, Matsunari, and then makes an abrupt change in a northerly direction towards Minami-i, and crosses the pass of Yenoki-zaka to Kōkita as far as the city of Fukui, in Echizen.

It will be seen from the map (Pl. XXIX), that the neighbourhood of Hikoné at the eastern border of Lake Biwa, was severely shaken and deeply damaged by the earthquake, whereas the stretch of land between this and the Mino-Owari plain suffered very little. Such an abnormal phenomenon had been already noticed by Kluge, long ago as 1861, when he says: "dass ein Erdbeben durch seine letzen, abgeschwächten Wellen an einem anderen, weit entfernten Punkte eine selbständige Erschütterung hervorrufen kann, die möglicherweise einen ganz anderen Ursprung hat, als dieses primäre Erdbeben. Es ist dies eine Erscheinung, welcher bis jetzt noch nicht die Beachtung gewidmet worden ist, welche sie verdient. Es giebt nämlich Stossgebiete, welche gewissermaassen den Wiederhall oder das Echo weit entfernter Erdbeben bilden, in denen zwar die Disposition zu einer Erderschutterung vorhanden ist, dieselbe aber häufig erst, wie es scheint, durch eine andere geweckt werden muss."* A. v. Lasaulx** named such an earthquake the sympathetic, or *Relaisbeben*. The destructive shocks near Hikoné, especially Nagahama, at the time of the great convulsion in the neighbouring provinces, seem to me to have been caused by the above-mentioned secondary earthquakes or *Relaisbeben*. It must, however, be remarked that the intensity of shocks felt on the surface has greatly to do with the *orographic* condition of the region concerned, besides the reason given by v. Lasaulx.

* *Ueber die Ursachen der in den Jahren 1850 bis 1857 stattgefundenen Erderschutterungen.*
** Kenngott's *Handwörterbuch der Mineralogie*, etc.

VII. Concluding Remarks.

Speaking generally, it may be said that all large earthquakes are accompanied by the formation of fissures. The cracks, fissures, and slips formed at the time of earthquakes are of *various natures*, and of *different dimensions*. Some occur along a road, or run near the upper edge of a cliff. The reason that cracks should have occurred in such a position as the latter rather than in others is probably owing to the greater motion at such a place, due to the face of the cliff being unsupported and with nothing opposed to its outward motion. Similar remarks may be applied to the banks of rivers and to all depressions, whether natural or artificial, which have a steeep slope. At such places the waves of the shocking emerge on a free surface, tending to project the superficial parts away from those behind, and thus form a fissure parallel to the free surface.

Moreover, slips and fissures depend upon the *structure of rocks*, and occur on a particularly grand scale where the strata dip into or against the slope of the walls of a valley. We have numerous examples of this in all the side-valleys of the Neo river, which run parallel to the strike of a complex of clay-slates, sandstones, and hornstone-slates, the main course of the river, as already stated, being directed against the strike of the Palæozoic formations. This often misled observers to see in the side-valleys the seat of the origin of the earthquake, because the shocks were far more destructive there than in other places. *However great the destruction was, it was nothing more than the superficial effects of the earthquake, but not the cause of it.* There are other fissures, slips, and cracks of great geological importance, and of quite different origin, which should by no means be confounded with those already mentioned; as has unfortunately been

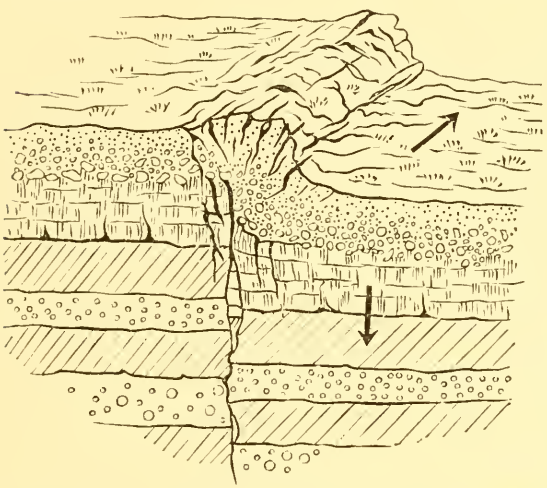
often done. They are really connected with underground structure and are due to displacement of the rock-masses which constitute the external crust of the earth. They therefore occur where there exists a discontinuity of rocks, and the earth-rent which we have described, and which is the main point in the present paper, must be regarded as an example.

This rent at the surface took multifarious forms. When traversing a ridge of mountains or a spur of hills, it caused extensive landslips, one side of it descending considerably in level, carrying the forest with it, but with the trees complicatedly interlocked or prostrate on the ground, as on the ridge of Haku-san. On flat ground it sometimes created a terrace of about 6 metres in height, as in Midori (Pl. XXXIV.), somewhat like a railway embankment seen from afar. When the vertical displacement was not very considerable, the earth-rent left a mark on the ground, *resembling very much the pathway of a gigantic mole or the track of a plough-share* (Pl. XXXV.).

The manner in which this peculiar low mound was formed may be explained by reference to a monoclinal flexure—a geological structure well exhibited on a grand scale in the Plateau of Wahsatch.* Suppose the flat bottom of a valley like the Neo, filled up with soil and gravel which rest unconformably upon the hard mass of the older rocks, and form their 'cover,' and that the basement should give way by faulting along the vertical thrust-plane; there a certain portion of the uncompressed 'cover' will thereby be uplifted, so as to form a rounded ridge of earth by the lateral compression of a subjacent mass along the line of discontinuity. In this way a monoclinal flexure in the loose superficial covering, which appears in section as a flexure connecting two horizontal bars of strata, would be

* C. E. Dutton, *Report on the Geology of the High Plateaus of Utah*, p. 25-54.

produced by direct lateral pressure exerted at the ends of the bars.* Besides the vertical movement, horizontal shifting of either side would take place along the same plane of fault, and the raised ridge would be much disturbed and become a confused mass of clods of earth, as shown in the subjoined wood-cut. The flexure in this case had better be called the *monoclinic diagonal flexure*. The peculiar soft mound of earth, of which we have often spoken, belongs to such a flexure.



This unique track, though at first sight it seemed quite insignificant and was consequently usually overlooked by casual observers, is of great geological bearing. Unlike other accidental fissures it is characterized by constancy of direction and regularity of course. Starting from Katabira near the Kiso-gawa, it runs up its length through the Neo valley to Haku-san (a distance of 64 kilometres), and then seems to proceed north-west up to the city of Fukui, for the extraordinary distance of 112 kilometres, or 28 *ri*. The one with which we are most concerned, is the line of fault or displacement of rock-complexes, along which, as I have repeatedly pointed out, the ground on the *left side had subsided from* $\frac{2}{3}$ *to 6 metres, and at the same time been horizontally shifted for* $1\frac{2}{3}$ *to 2 metres in a north-westerly direction*. The only exception to the general rule was the fault in Midori, where the land was lower on the west than on the east; the manner in which this special condition may be supposed to have been

* See *The cause of Monoclinal Flexure*, by A. J. Jukes-Brown, Geol. Mag. 1891, p. 505.

brought about, has been already stated, namely, that it was the east half, which was *elevated* through some local circumstances and not the west side depressed.

In regard to alterations of relative level, none of my observations, however, establish which side it was that moved, or whether both moved but in a different manner. It must always be remembered that to ascertain a change of level is a subject of considerable difficulty almost incapable of determination, except where the sea-coast happens to have participated in the principal movement. In the last earthquake we had no opportunity of observing such phenomena on the sea-coast, either of the Pacific Ocean or of the Japan Sea; probably because of the line of the principal fissure being entirely confined to the interior. Had it been possible to observe the fissure on the shore, it might even then have been impossible to determine whether an elevation or a depression, even of several metres, had occurred, because there would be usually nothing at that point to mark the mean sea-level.

As data on which I could rely, in ascertaining the actual instead of the relative change of level of the ground, were not at my disposal, it seems to me very natural to suppose that it was subsidence rather than upheaval which took place along the line of the shift; and it is the eastern wing which stands usually at the lower level. But it is another problem to be solved how far this depression extends easterly; whether the whole of Eastern Japan participated in the downward movement, as in the "sunk country" of New Madrid,* created at the time of the great earthquake of 1811-12, or the "sag" or *Graben* of the Lake of Baikal, at the mouth of the Senega river,** or whether the movement was limited to only a few kilometres to

* Lyell, *Principles of Geology*, 12th edition, Vol. II, p. 108.

** Perry, *Note on the Earthquake of* 1862, cited by Suess, in his *Das Antlitz der Erde* Bd. I, p. 14.

the east. So far as my local knowledge extends, there seems to exist only one regular line of shift in the convulsed district, from which we may fairly conclude that the subsidence attending it, is not of the kind called "sag;" and I do not believe that the half of Japan sunk down, but that only the land near the line of fault became slightly depressed.

Of every large earthquake, we find the accounts full of the mutations which the earth underwent through the agency of subterranean movements; for instance, the formation of cracks and fissures, besides permanent upheavals and depressions, accompanied usually by spirting up of the squeezed groundwater and sliding of detached portions of the mountain-sides. Of movements like these, that of the *Ullah Bund*, in the delta of the Indus, is the most remarkable. The real occurrence of the much talked of rhapsodic movements along the western shore of South America, is not entirely free from doubt. Immediately after the convulsion of 1819, the inhabitants of Sindree, in the Runn of Cutch, saw at a distance a long elevated mound, where previously there had been a low and perfectly level plain. To this terraced tract they gave the name of 'Ullah Bund,' or the 'Mound of God,' to distinguish it from several artificial dams previously thrown across the eastern arm of the Indus.*

This 'Ullah Bund' seems from its description to have a close resemblance in its outward aspect, to the fault at Midori, in the Neo valley. As to the manner in which the 'Mound of God' was formed, the views of geologists are divided. Lyell saw in this newly created dam a true upheaving of the ground, while Suess considers it in another point of view. Suess** says, "*Es handelt sich hier weder um Erhebung von Land, noch, wie ich selbst einmal, irregeführt durch andere*

* Lyell, *loc. cit.* p. 100.

** *Das Antlitz der Erde*, Bd. I, p. 62, and *Entstehung der Alpen*, p. 152.

Darstellungen, vermuthet habe, um Faltenbildung an der Oberfläche, sondern nur um das Hervordringen von Grundwasser und des Nachsitzen eines scharf abgegrenzten Theiles des schlammigen Bodens." Suess explains in similar manner the formation of the '*sunk country*' of New Madrid, the depression of Baikal Lake, and those subsidences at the mouths of the Ganges and the Brahmaputra, at the time of violent earthquakes. *They were not, according to him, connected with deep-seated movements altering the relative level of sea and land.*

The great fault of Neo, by which I mean that long line of earth-rent which traverses a distance of 112 kilometres from the Kiso-gawa to the city of Fukui, cutting the hills, mountains, and plains alike with remarkable regularity and sharpness, is clearly not like that of the Ullah Bund, caused by the mere settling of superficial Alluvial soil.

The sudden elevations, depressions, or lateral shiftings of large tracts of country which take place at the time of destructive earthquakes are *usually considered as the effects rather than the cause* of subterranean commotions; *but in my opinion, it can be confidently asserted that the sudden formation of the 'great fault of Neo' was the actual cause of the great earthquake of the 28th of October, 1891, which shook an area comprising 243,055 square kilometres, or more than 60% of the whole extent of the Empire of Japan;* that is to say, an area equal to those of the British Isles, Holland, and Denmark put together.

It is an established tenet of geology that a sudden faulting of the earth's crust will cause a shaking which is designated by the general term of *tectonic earthquake.* The faults resulting from tangential movements are of two classes, those running parallel to the strike of rock-complexes, across the axis of mountain-ranges. All kinds of tectonic earthquake are usually considered destructive and extensive, as compared with those caused by a depression or by a volcanic

explosion; and of all the tectonic earthquakes a sudden faulting of the solid crust *across* the strike of strata are said to produce the most fearful kind of earth-movements, as is evinced by the Spanish earthquake of 1884, along the transverse fractures of Malaga, Motril, and Guadix across the Betic chain of Andalusia* (Suess' *Blätterbeben*). One of the characteristics of the transverse faulting is the simultaneous occurrence of the horizontal 'carriage' of a thick mass along the vertical thrust-plane, which is very rarely observed, if ever, in longitudinal fissures.

The backbone of South Japan—the cordilleras of the Sinical system, traverses the boundary of the two provinces of Mino and Echizen, in the east-west direction, with the prevailing dips of the Palæozoic formations towards the north, as is shown in Pl. XXVIII. A system of parallel, transverse valleys intersects the axis of the mountains in an oblique direction from north-west to south-east, and the Neo valley, along which the 'great earth-rent of Neo' going deep into the rocky crust was produced, is one of these. *A sudden falling of the Palæozoic strata on the right wing along the line of the 'fault of Neo,' accompanied by lateral shifting toward the north-west, caused the shaking which constituted the late dreadful catastrophe of Mino, Owari, and Echizen.*

I wish here to express my thanks to Professors Edward Divers and Dairoku Kikuchi for their kindness in undertaking a laborious and time-wasting work to see the paper through the press.

April, 1892, Geological Institute of the College of Science.

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* *Mission d'Andalousie : Études relatives au tremblement du terre du 25. Décembre 1884, Mem. Acad. des Sciences*, T. XXX.

PLATE XXVIII.

Plate XXVIII.

This plate is intended to show the geological formations and structures, in general of the Mino-Owari plain; the positions of the line of section a-b,and c-d are indicated with corresponding letters by the heavily dotted (red) lines in Plate XXIX.

The upper section a-b, representing Palæozoic formations, is drawn from Yamasaki in Owari through the ridges of Yōrō and Fujiwara to Yominadō in Ōmi.

SC,—sandstone and clayslate; | Q,—quartz-porphyry;
L,—limestone; | GR,—granite.

The lower section c-d, likewise of the Palæozoic complex, is taken in a north, westerly direction from Yamaguchi near Gifu along the Neo valley up to Haku-san. The rock represented are the sandstone and clayslate, hornstone and fossiliferous limestone; the mass of Haku-san being made up of granite-porphyry.

W
E
a
b
Q
GR
SC
L
Mt. Fujiwara
Tertiary
Scale — 1/200000 Vertical × 2
NW
SE
GP
L2
L1
c
d
Scale — 1/400000 Vertical × 20

PLATE XXIX.

Plate XXIX.

Topographic map, published by the Geological Survey, representing the earthquake district of Central Japan between the Japan Sea and the Bay of Ise. The heavy red line indicates the course of the great fault from Katabira in Mino to Fukui in Echizen, the shaded portion being the meizoseismic area. The dotted lines A-B, and C-D show the direction of sections, given separately in Pl. XXVIII.

MAP OF THE EARTHQUAKE DISTRICT.

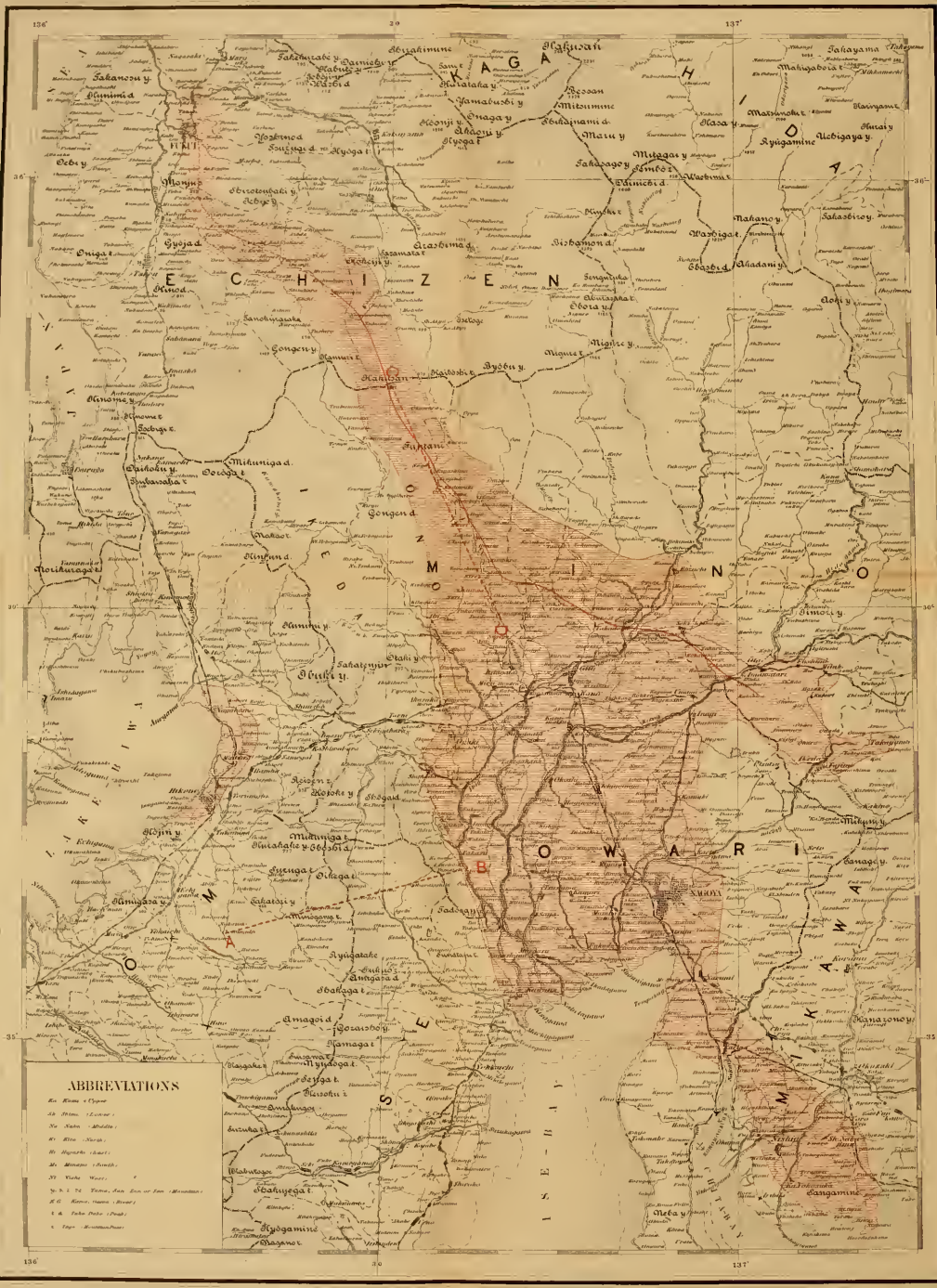

PLATE XXX.

Plate XXX.

General plan for the geological structure of Mino, Owari, and Echizen, in which are shown the regular course (blue lines) of valleys from N. W. to S. E., indicating the positions of the pre-existing transverse fault, and the black lines being the direction of the strike of Palæozoic complex, with the dips as marked with the arrow-heads. The heavy red line is the course of the 'great fault of Neo'.

Fukui
The Great Neo Fault Line
Boundary Range of Mino-Echizen
Tokuyama Valley
Neo Valley
Nugi Valley
Hatori Valley
Ibuki
Gifu
MINO-OWARI PLAIN
Nagoya
Suzuka
Yoro
Fault-Line.
Strike of Palaeozoic Rocks.
Valleys.

PLATE XXXI.

Plate XXXI.

The upper picture shows thatched roofs fallen intact, and it was in this manner that most of farmers' cottages gave way, presenting the appearance of gigantic saddles, when seen from a distance.

The lower picture is the representation of the banks of the Shōnai-gawa near Biwashima, a suburb of Nagoya, fractured for a mile's length, parallel to the course of the river.

Fig. 1

Fig. 2

Collotype by K. OGAWA.

PLATE XXXII.

Plate XXXII.

Fig. 1.—A view of Kitakata (5 kilometres west of Gifu) after the earthquake, showing the rows of houses thrown over by shocks, and the road became simply a narrow lane between two interminable heaps of *debris*.

Fig. 2.—A very strange horizontal shifting of earth along the Shōnai-gawa, near Nagoya, by which the ground together with a large bamboo grove and a fallen thatched roof slid bodily some sixty feet westwards, the bamboo grove and a few pine trees remaining upright.

Fig. 1

Fig. 2

COLLOTYPE BY K. OGAWA.

PLATE XXXIII.

Plate XXXIII.

The map of the neighbourhood of Kumamoto in the island of Kiū-shū, compiled by myself from various sources. It shows the seat of source of the earthquake in 1889, in the extinct volcano of Kimposan (Kibō-zan) with an old somma around it. A-B, C-D, and C-E are the lines of fissure, formed at the time of the severe shocks; the shaded (blue) portion being the meizoseismic area in which buildings had been all more or less damaged. A portion of the city of Kumamoto, shaded in red, had been intensely shaken, on account of its being once marshy ground of which we have many historical proofs.

Tomio
Tsumana
Shimoda
Ryôhasama
Kawaiida
Simomura
Shimona
Kiyomizu
Imafuji
Ryûganji
Toyoda
Tsuigi
Takase
Tsuru
Uchimura
Kamenokô
Mukôtsuru
Hirubara
Suzumugi
Ôi
Terada
Konoha
Yamamoto
Mitori
Ôkura
Tasaki
Toyooka
Tominô
Kitasakamonta
Aono
Shiroki
Hitotsuki
Iroano
Futamata
Kurokake
Ono
Onojiri
Ikurakitakata
Nakasakamonta
Uchirokoga
Ueki
Kitamura
Haraminamikata
Todoroki
Hirozumi
Nobeta
Minamisakamonta
Nachi
Kamishiroki
Hirano
Natatsuka
Yomoki
Kaiki
Yokoshima
Oda
Entaji
Saiaiji
Hagizama
Harakura
Kusuno
Ôtori
Betami
Uchoga
Abumita
Kitome
Kajio
Tachibana
Hetumi
Kitazama
Kanokogi
Nishikajio
Yokoshimashinchi
Tarôzama
Suzurikawa
Yamogi
Manrakuji
Izumi
Shimosuzurikawa
Hira
Tômonji
Mitsugi
Yamamuradô
Shirahama
Tokuô
Takahiru
Kamau
Matsuzuke
Hamazono
Ichikoshi
Iheda
Funatsu
Ômoki
Tsunagira
Kuboji
Kamachi
Hirayama
Shimosaki
Miyauchi
KUMAMOTO
Tosaka
Chikatsu
Yokote
Shinyashiki
Kamimatsua
Tsubotsuna
Ikenoue
Harutake
Kasuga
Tokuhashi
Toyasu
Hachiji
Shimomatsuo
Ômo
Tasaki
Hiraki
Ôjima
Kamitai
Shimotai
Shindogamera
Tamukai
Shirakawa
Chikami
Ogishu
Shimoshin
Nakajima
Imamura
Sunabara
Shimamura
Idenokama
Gôshi
Tukue
Fueda
Magodai
Hafuji
Shirafuji
Nishimada
Shigetomi
Namitate
Shiraishi
Fukamachi
Aitomi
Tarouta
Uchida
Motomi
Gotô
Kanajiri
Kabe
Ôkukoga
Shimonakano
Nakamuda
Nada
Eguchi
Mitori
Shakadô
Kawaguchi
Nihonmiya
Komonge
Ômachi
Kimpôzan
Aragayama
Hanaohayama
Somma
A
B
C
D
E
MAP
OF THE
ENVIRONS OF KUMAMOTO
Scale 1: 20000

PLATE XXXIV.

Plate XXXIV.

Amongst the extraordinary works done by the earthquake, the fault in Midor is the most remarkable. A fine new road had been obliquely cut into two, and the west half with the surrounding fields had sunk about 6 metres below the upper end. The eastern half had been pushed 4 metres northwards, as is well seen in the photograph by an abrupt change in the direction of the displaced road.

Collotype by K. Ogawa.

Plate XXXV.

The plough-share-like appearance of fault near Fujitani in the Neo valley, along which again the depressed eastern wing, in conformation to the general rule, had been shifted in a northerly direction.

Collotype by K. OGAWA.

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